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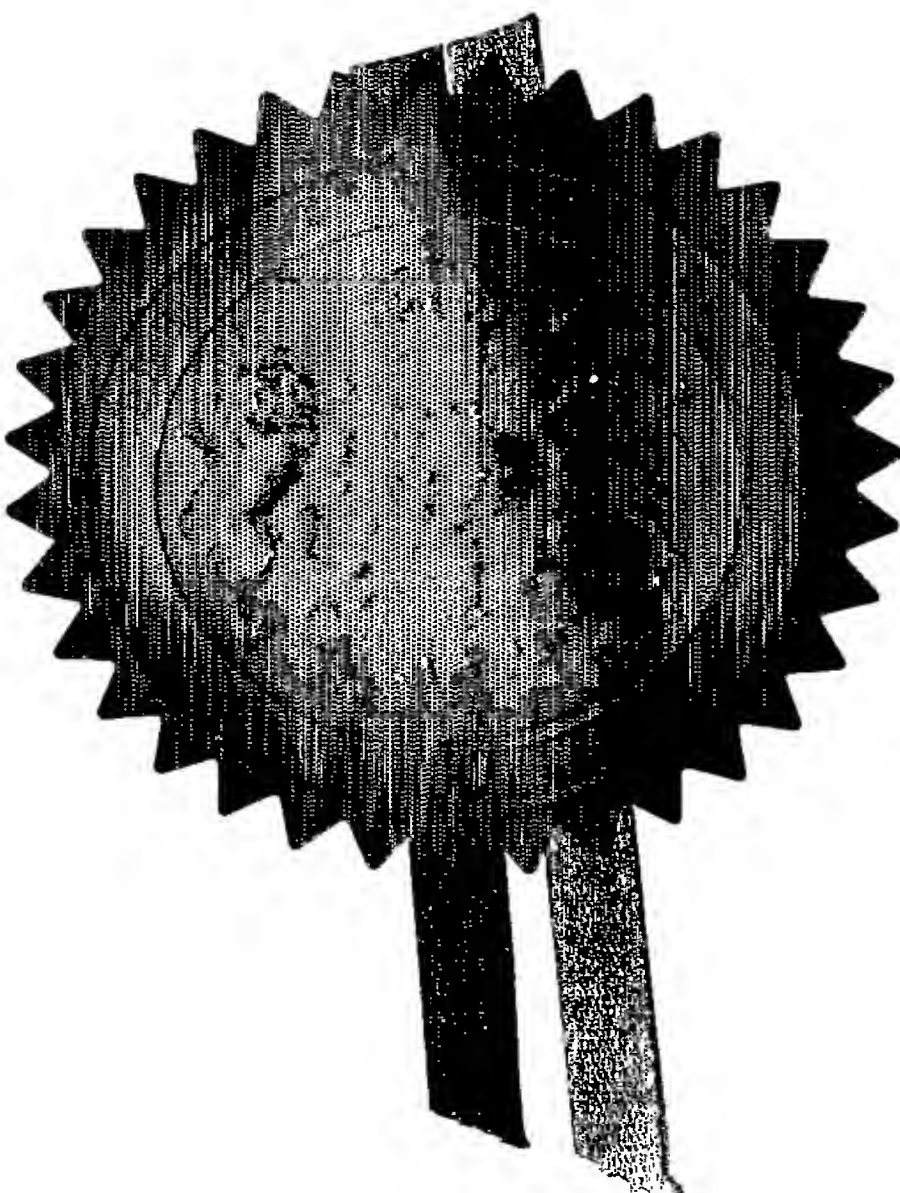
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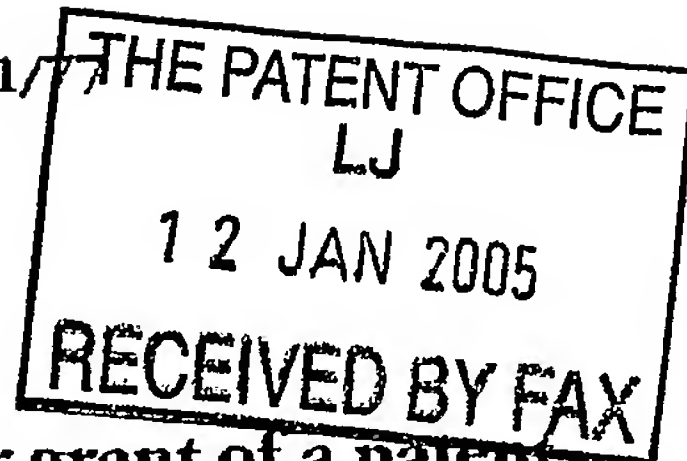


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3. Full name, address and postcode of the or of each applicant (underline all surnames)

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Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

08333072001

4. Title of the invention

 "Improvements in or Relating to a Method and Apparatus for
 Generating a Mist"

5. Name of your agent (if you have one)

Murgitroyd & Company

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 to which all correspondence should be sent
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00001198015

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1 **Improvements in or Relating to Method and Apparatus**
2 **for Generating a Mist**

3

4 The present invention relates to improvements in or
5 relating to a method and apparatus for generating a
6 mist.

7

8 It is well known in the art that there are three
9 major contributing factors required to maintain
10 combustion. These are known as the fire triangle,
11 i.e. fuel, heat and oxygen. Conventional fire
12 extinguishing and suppression systems aim to remove
13 or at least minimise at least one of these major
14 factors. Typically fire suppression systems use
15 inter alia water, CO₂, Halon, dry powder or foam.
16 Water systems act by removing the heat from the
17 fire, whilst CO₂ systems work by displacing oxygen.

18

19 Another aspect of combustion is known as the flame
20 chain reactions. The reaction relies on free
21 radicals that are created in the combustion process
22 and are essential for its continuation. Halon

1 operates by attaching itself to the free radicals
2 and thus preventing further combustion by
3 interrupting the flame chain reaction.
4

5 The major disadvantage of water systems is that a
6 large amount of water is usually required to
7 extinguish the fire. This presents a first problem
8 of being able to store a sufficient volume of water
9 or quickly gain access to an adequate supply. In
10 addition, such systems can also lead to damage by
11 the water itself, either in the immediate region of
12 the fire, or even from water seepage to adjoining
13 rooms. CO2 and Halon systems have the disadvantage
14 that they cannot be used in environments where
15 people are present as it creates an atmosphere that
16 becomes difficult or even impossible for people to
17 breathe in. Halon has the further disadvantage of
18 being toxic and damaging to the environment. For
19 these reasons the manufacture of Halon is being
20 banned in most countries.
21

22 To overcome the above disadvantages a number of
23 alternative systems utilising liquid mist have
24 emerged. The majority of these utilise water as the
25 suppression media, but present it to the fire in the
26 form of a water mist. A water mist system overcomes
27 the above disadvantages of conventional systems by
28 using the water mist to reduce the heat of the
29 vapour around the fire, displace the oxygen and also
30 disrupt the flame chain reaction. Such systems use
31 a relatively small amount of water and are generally

1 intended for class A and B fires, and even
2 electrical fires.

3

4 Current water mist systems utilise a variety of
5 methods for generating the water droplets, using a
6 range of pressures. A major disadvantage of many of
7 these systems is that they require a relatively high
8 pressure to force the water through injection
9 nozzles and/or use relatively small nozzle orifices
10 to form the water mist. Typically these pressures
11 are 20bar or greater. As such, many systems utilise
12 a gas-pressurised tank to provide the pressurised
13 water, thus limiting the run time of the system.
14 Such systems are usually employed in closed areas of
15 known volume such as engine rooms, pump rooms, and
16 computer rooms. However, due to their finite
17 storage capacity, such systems have the limitation
18 of a short run time. Under some circumstances, such
19 as a particularly fierce fire, or if the room is no
20 longer sealed, the system may empty before the fire
21 is extinguished. Another major disadvantage of these
22 systems is that the water mist from these nozzles
23 does not have a particularly long reach, and as such
24 the nozzles are usually fixed in place around the
25 room to ensure adequate coverage.

26

27 Conventional water mist systems use a high pressure
28 nozzle to create the water droplet mist. Due to the
29 droplet formation mechanism of such a system, and
30 the high tendency for droplet coalescence, an
31 additional limitation of this form of mist
32 generation is that it creates a mist with a wide

1 range of water droplet sizes. It is known that
2 water droplets of approximately 40-50µm in size
3 provide the optimum compromise for fire suppression.
4 for a number of fire scenarios. For example, a
5 study by the US Naval Research Laboratories found
6 that a water mist with droplets less than 42µm in
7 size was more effective at extinguishing a test fire
8 than Halon 1301. A water mist systems comprised of
9 droplets in the approximate size range of 40-50µm
10 provides an optimum compromise of having the
11 greatest surface area for a given volume, whilst
12 also providing sufficient mass to project a
13 sufficient distance and also penetrate into the heat
14 of the fire. Conventional water mist systems
15 comprised of droplets with a lower droplet size will
16 have insufficient mass, and hence momentum, to
17 project a sufficient distance and also penetrate
18 into the heat of a fire.

19
20 The majority of conventional water mist systems only
21 manage to achieve a low percentage of the water
22 droplets in this key size range.

23
24 An additional disadvantage of the conventional water
25 mist systems, generating a water mist with such a
26 wide range of droplet sizes, is that the majority of
27 fire suppression requires line-of-sight operation.
28 Although the smaller droplets will tend to behave as
29 a gas the larger droplets in the flow will
30 themselves impact with these smaller droplets so
31 reducing their effectiveness. A mist which behaves
32 more akin to a gas cloud has the advantages of

1 reaching non line-of-sight areas, so eliminating all
2 hot spots and possible re-ignition zones. A further
3 advantage of such a gas cloud behaviour is that the
4 water droplets have more of a tendency to remain
5 airborne, thereby cooling the gases and combustion
6 products of the fire, rather than impacting the
7 surfaces of the room. This improves the rate of
8 cooling of the fire and also reduces damage to items
9 in the vicinity of the fire.

10

11 A water mist comprised of droplets with a droplet
12 size less than 40µm will improve the rate of cooling
13 the fire and also reduce damage to items in the
14 vicinity of the fire. However, such droplets from
15 conventional systems will have insufficient mass,
16 and hence momentum, to project a sufficient distance
17 and also penetrate into the heat of a fire.

18

19 According to a first aspect of the present invention
20 there is provided apparatus for generating a mist
21 comprising:

22 a conduit having a mixing chamber and an exit;
23 a working fluid inlet in fluid communication
24 with said conduit;

25 a transport nozzle in fluid communication with
26 the said conduit, the transport nozzle adapted to
27 introduce a transport fluid into the mixing chamber;
28 the transport nozzle having an angular orientation
29 and internal geometry such that in use the transport
30 fluid interacts with the working fluid introduced
31 into the mixing chamber through the working fluid
32 inlet to atomise and form a dispersed vapour/droplet

1 flow regime, which is discharged as a mist
2 comprising working fluid droplets, a substantial
3 portion of the droplets having a size less than
4 20 μ m.

5
6 Preferably the working fluid droplets have a
7 substantially uniform droplet distribution having
8 droplets with a size less than 20 μ m.

9
10 Typically at least 60% of the droplets by volume
11 have a size within 30% of the median size, although
12 the invention is not limited to this. In a
13 particularly uniform mist the proportion may be 70%
14 or 80% or more of the droplets by volume having a
15 size within 30%, 25%, 20% or less of the median
16 size.

17
18 Preferably the substantial portion of the droplets
19 has a cumulative distribution greater than 90%.

20
21 Optionally, a substantial portion of the droplets
22 have a droplet size less than 10 μ m.

23
24 Preferably the transport nozzle substantially
25 circumscribes the conduit.

26
27 Preferably the mixing chamber includes a converging
28 portion.

29
30 Preferably the mixing chamber includes a diverging
31 portion.

32

1 Preferably the internal geometry of the transport
2 nozzle has an area ratio, namely exit area to throat
3 area, in the range 1.75 to 15, having an included α -
4 angle substantially equal to or less than 6 degrees
5 for supersonic flow, and substantially equal to or
6 less than 12 degrees for sub-sonic flow.

7
8 Preferably the transport nozzle is oriented at an
9 angle β of between 0 to 30 degrees.

10
11 Preferably the transport nozzle is shaped such that
12 transport fluid introduced into the mixing chamber
13 through the transport nozzle has a divergent or
14 convergent flow pattern.

15
16 Preferably the transport nozzle has inner and outer
17 surfaces each being substantially frustoconical in
18 shape.

19
20 Preferably the apparatus further includes a working
21 nozzle in fluid communication with the conduit for
22 the introduction of working fluid into the mixing
23 chamber.

24
25 Preferably the working nozzle is positioned nearer
26 to the exit than the transport nozzle.

27
28 Preferably the working nozzle is shaped such that
29 working fluid introduced into the mixing chamber
30 through the working nozzle has a convergent or
31 divergent flow pattern.

32

1 Preferably the working nozzle has inner and outer
2 surfaces each being substantially frustoconical in
3 shape.

4
5 Preferably the apparatus further includes a second
6 transport nozzle being adapted to introduce further
7 transport fluid or a second transport fluid into the
8 mixing chamber.

9
10 Preferably the second transport nozzle is positioned
11 nearer to the exit than the transport nozzle.

12
13 Preferably the second transport nozzle is positioned
14 nearer to the exit than the working nozzle, such
15 that the working nozzle is located intermediate the
16 two transport nozzles.

17
18 Preferably the conduit includes a passage.

19
20 Preferably the inner wall of the passage is adapted
21 with a contoured portion to induce turbulence of the
22 working fluid upstream of the transport nozzle.

23
24 Preferably the mixing chamber includes an inlet for
25 the introduction of an inlet fluid.

26
27 Preferably the mixing chamber is closed upstream of
28 the transport nozzle.

29
30 Preferably the apparatus further includes a
31 supplementary nozzle arranged inside the transport
32 nozzle and adapted to introduce further transport

1 fluid or a second transport fluid into the mixing
2 chamber.

3

4 Preferably the supplementary nozzle is arranged
5 axially in the mixing chamber.

6

7 Preferably the supplementary nozzle extends forward
8 of the transport nozzle.

9

10 Preferably the supplementary nozzle is shaped with a
11 convergent-divergent profile to provide supersonic
12 flow of the transport fluid which flows
13 therethrough.

14

15 Preferably the apparatus further includes control
16 means adapted to control one or more of droplet
17 size, droplet distribution, spray cone angle and
18 projection distance.

19

20 Preferably the apparatus further includes control
21 means to control one or more of the flow rate,
22 pressure, velocity, quality, and temperature of the
23 inlet and/or working and/or transport fluids.

24

25 Preferably the control means includes means to
26 control the angular orientation and internal
27 geometry of the working and/or transport and/or
28 supplementary nozzles.

29

30 Preferably the control means includes means to
31 control the internal geometry of at least part of

1 the mixing chamber or exit to vary it between
2 convergent and divergent.

3
4 Preferably the exit of the apparatus is provided
5 with a cowl to control the mist.

6
7 Preferably the cowl comprises a plurality of
8 separate sections arranged radially, each section
9 adapted to control and re-direct a portion of the
10 discharge of mist emerging from the exit.

11
12 Preferably the apparatus is located within a further
13 cowl.

14
15 Preferably at least one of the transport,
16 supplementary or working nozzles is adapted with a
17 turbulator to enhance turbulence.

18
19 According to a second aspect of the present
20 invention there is provided a method of generating a
21 mist comprising the steps of:

22 providing apparatus for generating a mist
23 comprising a transport nozzle and a conduit, the
24 conduit having a mixing chamber and an exit;

25 introducing a stream of transport fluid into
26 the mixing chamber through the transport nozzle;

27 introducing a working fluid into the mixing
28 chamber;

29 atomising the working fluid by interaction of
30 the transport fluid with the working fluid to form a
31 dispersed vapour/droplet flow regime; and

1 discharging the dispersed vapour/droplet flow
2 regime through the exit as a mist comprising working
3 fluid droplets, a substantial portion of the
4 droplets having a size less than 20 μ m.
5
6 Preferably the apparatus is an apparatus according
7 to the first aspect of the present invention.
8
9 Preferably the stream of transport fluid introduced
10 into the mixing chamber is annular.
11
12 Preferably the working fluid is introduced into the
13 mixing chamber via an inlet of the mixing chamber of
14 the apparatus.
15
16 Preferably the working fluid is introduced into the
17 mixing chamber via a working nozzle in fluid
18 communication with the conduit of the apparatus.
19
20 Preferably an inlet fluid is introduced into the
21 mixing chamber via an inlet of the mixing chamber of
22 the apparatus.
23
24 Preferably the method includes the step of
25 introducing the transport fluid into the mixing
26 chamber in a continuous or discontinuous or
27 intermittent or pulsed manner.
28
29 Preferably the method includes the step of
30 introducing the transport fluid into the mixing
31 chamber as a supersonic flow.
32

1 Preferably the method includes the step of
2 introducing the transport fluid into the mixing
3 chamber as a sub-sonic flow.
4
5 Preferably the method includes the step of
6 introducing the working fluid into the mixing
7 chamber in a continuous or discontinuous or
8 intermittent or pulsed manner.
9
10 Preferably the mist is controlled by modulating at
11 least one of the following parameters:
12 the flow rate, pressure, velocity, quality
13 and/or temperature of the transport fluid;
14 the flow rate, pressure, velocity, quality
15 and/or temperature of the working fluid;
16 the flow rate, pressure, velocity, quality
17 and/or temperature of the inlet fluid;
18 the angular orientation of the transport and/or
19 working and/or supplementary nozzle(s) of the
20 apparatus;
21 the internal geometry of the transport and/or
22 working and/or supplementary nozzle(s) of the
23 apparatus; and
24 the internal geometry, length and/or cross
25 section of the mixing chamber.
26
27 Preferably the mist is controlled to have a
28 substantial portion of its droplets having a size
29 less than 20 μ m.
30

- 1 Preferably the mist is controlled to have a
- 2 substantial portion of its droplets having a size
- 3 less than 10 μ m.
- 4
- 5 Preferably the method includes the generation of
- 6 condensation shocks and/or momentum transfer to
- 7 provide suction within the apparatus.
- 8
- 9 Preferably the method includes inducing turbulence
- 10 of the inlet fluid prior to it being introduced into
- 11 the mixing chamber.
- 12
- 13 Preferably the method includes inducing turbulence
- 14 of the working fluid prior to it being introduced
- 15 into the mixing chamber.
- 16
- 17 Preferably the method includes inducing turbulence
- 18 of the transport fluid prior to it being introduced
- 19 into the mixing chamber.
- 20
- 21 Preferably the transport fluid is steam or an
- 22 air/steam mixture.
- 23
- 24 Preferably the working fluid is water or a water-
- 25 based liquid.
- 26
- 27 Preferably the mist is used for fire suppression.
- 28
- 29 Preferably the mist is used for decontamination.
- 30
- 31 Preferably the mist is used for gas scrubbing.
- 32

1 Embodiments of the present invention will now be
2 described, by way of example only, with reference to
3 the accompanying drawings in which:

4
5 Fig. 1 is a cross-sectional elevation view of an
6 apparatus for generating a mist in accordance with a
7 first embodiment of the present invention;

8
9 Figs. 2 to 7 show alternative arrangements of a
10 contoured passage to initiate turbulence;

11
12 Fig. 8 is a cross sectional view of the apparatus of
13 Fig. 1 located in a casing;

14
15 Fig. 9 is a cross-sectional elevation view of an
16 alternative embodiment of the apparatus of Fig 1,
17 including a working nozzle;

18
19 Figs. 10 to 12 are schematics showing an over
20 expanded transport nozzle, an under expanded
21 transport nozzle, and a largely over expanded
22 transport nozzle, respectively;

23
24 Fig. 13 is a schematic showing the interaction of a
25 transport and working fluid as they issue from a
26 transport and working nozzle;

27
28 Fig. 14 is a cross-sectional elevation view of an
29 alternative embodiment of the apparatus of Fig. 9
30 having a diverging mixing chamber;

31

1 Fig. 15 is a cross-sectional elevation view of an
2 alternative embodiment of the apparatus of Fig. 14
3 having an additional transport nozzle;
4

5 Fig. 16 is a cross-sectional elevation view of an
6 apparatus for generating a mist in accordance with a
7 further embodiment of the present invention;
8

9 Fig. 17 is a cross-sectional elevation view of an
10 apparatus for generating a mist in accordance with
11 yet a further embodiment of the present invention;
12

13 Fig. 18 is a cross-sectional elevation view of an
14 alternative embodiment of the apparatus of Fig. 17
15 having an additional transport nozzle;
16

17 Fig. 19 is a cross-sectional elevation view of an
18 apparatus for generating a mist in accordance with a
19 further embodiment of the present invention;
20

21 Fig. 20 is a cross-sectional elevation view of an
22 alternative embodiment of the apparatus of Fig. 19
23 having an additional transport nozzle;
24

25 Fig. 21 is a cross-sectional elevation view of an
26 apparatus for generating a mist in accordance with a
27 further embodiment of the present invention;
28

29 Fig. 22 is a cross-sectional elevation view of an
30 alternative embodiment of the apparatus of Fig. 21
31 having a modification; and
32

1 Fig. 23 is a graph showing performance data of an
2 embodiment of the present invention.

3
4 Where appropriate, like reference numerals have been
5 substantially used for like parts throughout the
6 specification.

7
8 Referring to Fig. 1 there is shown an apparatus for
9 generating a mist, a mist generator 1, comprising a
10 conduit or housing 2 defining a passage 3 providing
11 an inlet 4 for the introduction of a working fluid
12 to be atomised, an outlet or exit 5 for the
13 emergence of a mist plume, and a mixing chamber 3A,
14 the passage 3 being of substantially constant
15 circular cross section.

16
17 The passage 3 may be of any convenient cross-
18 sectional shape suitable for the particular
19 application of the mist generator 1. The passage 3
20 shape may be circular, rectilinear or elliptical, or
21 any intermediate shape, for example curvilinear.

22
23 The mixing chamber 3A is of constant cross-sectional
24 area but the cross-sectional area may vary along the
25 mixing chamber's length with differing degrees of
26 reduction or expansion, i.e. the mixing chamber may
27 taper at different converging-diverging angles at
28 different points along its length. The mixing
29 chamber may taper from the location of the transport
30 nozzle 16 and the taper ratio may be selected such
31 that the multi-phase flow velocity and trajectory is
32 maintained at its optimum or desired position.

1
2 The mixing chamber 3A is of variable length in order
3 to provide a control on the mist emerging from the
4 mist generator 1, i.e. droplet size, droplet
5 density/distribution, projection range and spray
6 cone angle. The length of the mixing chamber is
7 thus chosen to provide the optimum performance
8 regarding momentum transfer and to enhance
9 turbulence. In some embodiments the length may be
10 adjustable in situ rather than pre-designed in order
11 to provide a measure of versatility.

12
13 The mixing chamber geometry is determined by the
14 desired and projected output performance of the mist
15 and to match the designed steam conditions and
16 nozzle geometry. In this respect it will be
17 appreciated that there is a combinatory effect as
18 between the various geometric features and their
19 effect on performance, namely droplet size, droplet
20 density, mist spray cone angle and projected
21 distance.

22
23 The inlet 4 is formed at a front end of a protrusion
24 6 extending into the housing 2 and defining
25 exteriorly thereof a chamber or plenum 8 for the
26 introduction of a transport fluid into the mixing
27 chamber 3A, the plenum 8 being provided with a
28 transport fluid feed port 10. The protrusion 6
29 defines internally thereof part of the passage 3.

30
31 The transport fluid is steam, but may be any
32 compressible fluid, such as a gas or vapour, or may

1 be a mixture of compressible fluids. It is
2 envisaged that to allow a quick start to the mist
3 generator 1, the transport fluid can initially be
4 air. Meanwhile, a rapid steam generator or other
5 means can be used to generate steam. Once the steam
6 is formed, the air supply can be switched to the
7 steam supply. It is also envisaged that air or
8 another compressible fluid and/or flowable fluid can
9 be used to regulate the temperature of the transport
10 fluid, which in turn can be used to control the
11 characteristics of the plume, i.e. the droplet size,
12 droplet distribution, spray cone angle and
13 projection of the plume.

14
15 A distal end 12 of the protrusion 6 remote from the
16 inlet 4 is tapered on its relatively outer surface
17 14 and defines an annular transport nozzle 16
18 between it and a correspondingly tapered part 18 of
19 the inner wall of the housing 2, the nozzle 16 being
20 in fluid communication with the plenum 8.

21
22 The transport nozzle 16 is so shaped (with a
23 convergent-divergent portion) as in use to give
24 supersonic flow of the transport fluid into the
25 mixing chamber 3A. For a given steam condition,
26 i.e. dryness (quality), pressure, velocity and
27 temperature, the transport nozzle 16 is preferably
28 configured to provide the highest velocity steam
29 jet, the lowest pressure drop and the highest
30 enthalpy between the plenum and nozzle exit.
31 However, it is envisaged that the flow of transport
32 fluid into the mixing chamber may alternatively be

1 sub-sonic in some applications for application or
2 process requirements, or transport fluid and/or
3 working fluid property requirements. For instance,
4 the jet issuing from a sub-sonic flow will be easier
5 to divert compared with a supersonic jet.
6 Accordingly, a transport nozzle could be adapted
7 with deflectors to give a wider cone angle than
8 supersonic flow conditions. However, whilst sub-
9 sonic flow may provide a wider spray cone angle,
10 there is a trade-off with an increase in the mist's
11 droplet size; but in some applications this may be
12 acceptable.

13
14 Thus, the transport nozzle 16 corresponds with the
15 shape of the passage 3, for example, a circular
16 passage would advantageously be provided with an
17 annular transport nozzle circumscribing the said
18 passage.

19
20 It is anticipated that the transport nozzle 16 may
21 be a single point nozzle which is located at some
22 point around the circumference of the passage to
23 introduce transport fluid into the mixing chamber.
24 However, an annular configuration will be more
25 effective compared with a single point nozzle.

26
27 The term "annular" as used herein is deemed to
28 embrace any configuration of nozzle or nozzles that
29 circumscribe the passage 3 of the mist generator 1,
30 and encompasses circular, irregular, polygonal,
31 elliptical and rectilinear shapes of nozzle.

32

1 In the case of a rectilinear passage, which may have
2 a large width to height ratio, transport nozzles
3 would be provided at least on each transverse wall,
4 but not necessarily on the sidewalls, although the
5 invention optionally contemplates a full
6 circumscription of the passage by the nozzles
7 irrespective of shape. For example the mist
8 generator 1, could be made to fit a standard door
9 letterbox to allow fire fighters to easily treat a
10 house fire without the need to enter the building.
11 Size scaling is important in terms of being able to
12 readily accommodate differing designed capacities in
13 contrast to conventional equipment.

14
15 The transport nozzle 16 has an area ratio, defined
16 as exit area to throat area, in the range 1.75 to 15
17 with an included angle (α) substantially equal to or
18 less than 6 degrees for supersonic flow, and
19 substantially equal to or less than 12 degrees for
20 sub-sonic flow; although the included angle(α) may
21 be greater. The angular orientation of the
22 transport nozzle 16 is $\beta = 0$ to 30 degrees relative
23 to the boundary flow of the fluid within the conduit
24 at the nozzle's exit. However, the angle β may be
25 greater.

26
27 The transport nozzle 16 may, depending on the
28 application of the mist generator 1, have an
29 irregular cross section. For example, there may be
30 an outer circular nozzle having an inner ellipsoid
31 or elliptical nozzle which both can be configured to
32 provide particular flow patterns, such as swirl, in

1 the mixing chamber to increase the intensity of the
2 shearing effect and turbulence.

3

4 In operation the inlet 4 is connected to a source of
5 working fluid to be atomised, which is introduced
6 into the inlet 4 and passage 3. The feed port 10 is
7 connected to a source of transport fluid.

8

9 For fire fighting applications, typically the
10 working fluid is water, but may be any flowable
11 fluid or mixture of flowable fluids requiring to be
12 dispersed into a mist, e.g. any non-flammable liquid
13 or flowable fluid (inert gas) which absorbs heat
14 when it vaporises may be used instead of the water.

15

16 The transport nozzle 16 is conveniently angled
17 towards the working fluid in the mixing chamber to
18 occasion penetration of the working fluid. The
19 angular orientation of the transport nozzle 16 is
20 selected for optimum performance to enhance
21 turbulence which is dependent inter alia on the
22 nozzle orientation and the internal geometry of the
23 mixing chamber, to achieve a desired plume mist
24 exiting the exit 5. Moreover, the creation of
25 turbulence, governed inter alia by the angular
26 orientation of the transport nozzle 16, is important
27 to achieve optimum performance by dispersal of the
28 working fluid in order to increase acceleration by
29 momentum transfer and mass transfer.

30

31 Simply put, the more turbulence there is generated,
32 the smaller the droplet size achievable.

1

2 The transport fluid, steam, is introduced into the
3 feed port 10, where the steam flows into the plenum
4 8, and out through the transport nozzle 16 as a high
5 velocity steam jet.

6

7 The high velocity steam jet issuing from the
8 transport nozzle 16 impacts with the water with high
9 shear forces, thus atomising the water and breaking
10 it into fine droplets and producing a well mixed
11 two-phase condition constituted by the liquid phase
12 of the water, and the steam. In this instance, the
13 energy transfer mechanism of momentum and mass
14 transfer occasion's induction of the water through
15 the mixing chamber 3A and out of the exit 5. Mass
16 transfer will generally only occur for hot transport
17 fluids, such as steam.

18

19 In simple terms, the present invention uses the
20 transport fluid to slice up the working fluid. As
21 already touched on, the more turbulence you have,
22 the smaller the droplets formed.

23

24 The present invention has a primary break up
25 mechanism and a secondary break up mechanism to
26 atomise the working fluid. The primary mechanism is
27 the high shear between the steam and the water,
28 which is a function of the high relative velocities
29 between the two fluids, resulting in the formation
30 of small waves on the boundary surface of the water
31 surface, ultimately forming ligaments which are
32 stripped off.

1
2 The secondary break up mechanism involves two
3 aspects. The first is further shear break up, which
4 is a function of any remaining slip velocities
5 between the water and the steam. However, this
6 reduces as the water ligaments/droplets are
7 accelerated up to the velocity of the steam. The
8 second aspect is turbulent eddy break up of the
9 water droplets caused by the turbulence of the
10 steam. The turbulent eddy break up is a function of
11 transport nozzle exit velocities, local turbulence,
12 nozzle orientation (this effects the way the mist
13 interacts with itself), and the surface tension of
14 the water (which is effected by the temperature).

16 The primary break up mechanism of the working fluid
17 may be enhanced by creating initial instabilities in
18 the working fluid flow. Deliberately created
19 instabilities in the transport fluid/working fluid
20 interaction layer encourages fluid surface turbulent
21 dissipation resulting in the working fluid
22 dispersing into a liquid-ligament region, followed
23 by a ligament-droplet region where the ligaments and
24 droplets are still subject to disintegration due to
25 aerodynamic characteristics.

27 The interaction between the transport fluid and the
28 working fluid, leading to the atomisation of the
29 working fluid, is enhanced by flow instability.
30 Instability enhances the droplet stripping from the
31 contact surface of the flow of the working fluid. A
32 turbulent dissipation layer between the transport

1 and working fluids is both fluidically and
2 mechanically (geometry) encouraged ensuring rapid
3 fluid dissipation.

4
5 The internal walls of the flow passage immediately
6 upstream of the transport nozzle 16 exit may be
7 contoured to provide different degrees of turbulence
8 to the working fluid prior to its interaction with
9 the transport fluid issuing from the or each nozzle.

10
11 Fig. 2 shows the internal walls of the passage 3
12 provided with a contoured internal wall in the
13 region 19 immediately upstream of the exit of the
14 transport nozzle 16 is provided with a tapering wall
15 130 to provide a diverging profile leading up to the
16 exit of the transport nozzle 16. The diverging wall
17 geometry provides a deceleration of the localised
18 flow, providing disruption to the boundary layer
19 flow, in addition to an adverse pressure gradient,
20 which in turn leads to the generation and
21 propagation of turbulence in this part of the
22 working fluid flow.

23
24 An alternative embodiment is shown in Fig. 3, which
25 shows the internal wall 19 of the flow passage 3
26 immediately upstream of the transport nozzle 16
27 being provided with a diverging wall 130 on the bore
28 surface leading up to the exit of the transport
29 nozzle 16, but the taper is preceded with a step
30 132. In use, the step results in a sudden increase
31 in the bore diameter prior to the tapered section.
32 The step 'trips' the flow, leading to eddies and

1 turbulent flow in the working fluid within the
2 diverging section, immediately prior to its
3 interaction with the steam issuing from the
4 transport nozzle 16. These eddies enhance the
5 initial wave instabilities which lead to ligament
6 formation and rapid fluid dispersion.

7
8 The tapered diverging section 130 could be tapered
9 over a range of angles and may be parallel with the
10 walls of the bore. It is even envisaged that the
11 tapered section 130 may be tapered to provide a
12 converging geometry, with the taper reducing to a
13 diameter at its intersection with the transport
14 nozzle 16 which is preferably not less than the bore
15 diameter.

16
17 The embodiment shown in Fig. 3 is illustrated with
18 the initial step 132 angled at 90° to the axis of
19 the bore 3. As an alternative to this
20 configuration, the angle of the step 132 may display
21 a shallower or greater angle suitable to provide a
22 'trip' to the flow. Again, the diverging section
23 130 could be tapered at different angles and may
24 even be parallel to the walls of the bore 3.
25 Alternatively, the tapered section 130 may be
26 tapered to provide a converging geometry, with the
27 taper reducing to a diameter at its intersection
28 with the transport nozzle 16 which is preferably not
29 less than the bore diameter.

30
31 Figs. 4 to 7 illustrate examples of alternative
32 contoured profiles 134, 136, 138, 140. All of these

1 are intended to create turbulence in the working
2 fluid flow immediately prior to the interaction with
3 the transport fluid issuing from the transport
4 nozzle 16.

5
6 Although Figs. 2 to 7 illustrate several
7 combinations of grooves and tapering sections, it is
8 envisaged that any combination of these features, or
9 any other groove cross-sectional shape may be
10 employed.

11
12 Similarly, the transport, working and supplementary
13 nozzles, and the mixing chamber, may be adapted with
14 such contours to enhance turbulence.

15
16 The length of the mixing chamber 3A can be used as a
17 parameter to increase turbulence, and hence,
18 decrease the droplet size, leading to an increased
19 cooling rate.

20
21 The properties or parameters of the working fluid
22 and transport fluid, for example, flow rate,
23 velocity, quality, pressure and temperature, can be
24 regulated or controlled or manipulated to give the
25 required intensity of shearing and hence, the
26 required droplet formation. The properties of the
27 working and transport fluids being controllable by
28 either external means, such as a pressure regulation
29 means, and/or by the angular orientation (exit
30 angle) and internal geometry of the nozzle 16.

31

1 The quality of the inlet and working fluids refer to
2 its purity, viscosity, density, and the
3 presence/absence of contaminants.

4
5 The mechanism of the present invention primarily
6 relies on the momentum transfer between the
7 transport fluid and the working fluid, which
8 provides for shearing of the working fluid on a
9 continuous basis by shear dispersion and/or
10 dissociation, plus provides the driving force to
11 propel the generated mist out of the exit. However,
12 when the transport fluid is a hot compressible gas,
13 for example steam, i.e. the transport fluid is of a
14 higher temperature than the working fluid, it is
15 thought that this mechanism is further enhanced with
16 a degree of mass transfer between the transport
17 fluid and the working fluid as well. Again, when
18 the transport fluid is hotter than the working fluid
19 the heat transfer between the fluids and the
20 resulting increase in temperature of the working
21 fluid further aids the dissociation of the liquid
22 into smaller droplets by reducing the viscosity and
23 surface tension of the liquid.

24
25 The intensity of the shearing mechanism, and
26 therefore the size of the droplets created, and the
27 propelling force of the mist, is controllable by
28 manipulating the various parameters prevailing
29 within the mist generator 1 when operational.
30 Accordingly the flow rate, pressure, velocity,
31 temperature and quality, e.g. in the case of steam
32 the dryness, of the transport fluid, may be

1 regulated to give a required intensity of shearing,
2 which in turn leads to the mist emerging from the
3 exit having a substantial uniform droplet
4 distribution, a substantial portion of which have a
5 size less than $20\mu\text{m}$.

6
7 Similarly, the flow rate, pressure, velocity,
8 quality and temperature of the working fluid, which
9 are either entrained into the mist generator by the
10 mist generator itself (due to shocks and the
11 momentum transfer between the transport and working
12 fluids) or by external means, may be regulated to
13 give the required intensity of shearing and desired
14 droplet size.

15
16 In carrying out the method of the present invention
17 the creation and intensity of the dispersed droplet
18 flow is occasioned by the design of the transport
19 nozzle 16 interacting with the setting of the
20 desired parametric conditions, for example, in the
21 case of steam as the transport fluid, the pressure,
22 the dryness or steam quality, the velocity, the
23 temperature and the flow rate, to achieve the
24 required performance of the transport nozzle, i.e.
25 generation of a mist comprising a substantially
26 uniform droplet distribution, a substantial portion
27 of which have a size less than $20\mu\text{m}$.

28
29 The performance of the present invention can be
30 complimented with the choice of materials from which
31 it is constructed. Although the chosen materials
32 have to be suitable for the temperature, steam

1 pressure and working fluid, there are no other
2 restrictions on choice. For example, high
3 temperature composites could be used. For example,
4 high temperature composites, stainless steel, or
5 aluminium could be used.

6
7 The nozzles may advantageously have a surface
8 coating. This will help reduce wear of the nozzles,
9 and avoid any build up of agglomerates/deposits
10 therein, amongst other advantages.

11
12 The transport nozzle 16 may be continuous (annular)
13 or may be discontinuous in the form of a plurality
14 of apertures, e.g. segmental, arranged in a
15 circumscribing pattern that may be circular. In
16 either case each aperture may be provided with
17 substantially helical or spiral vanes formed in
18 order to give in practice a swirl to the flow of the
19 transport fluid and working fluid respectively.

20
21 Alternatively swirl may be induced by introducing
22 the transport/working fluid into the mist generator
23 in such a manner that the transport/working fluid
24 flow induces a swirling motion in to and out of the
25 transport nozzle 16. For example, in the case of an
26 annular transport nozzle, and with steam as the
27 transport fluid, the steam may be introduced via a
28 tangential inlet off-centre of the axial plane,
29 thereby inducing swirl in the plenum before passing
30 through the transport nozzle. As a further
31 alternative the transport nozzle may circumscribe
32 the passage in the form of a continuous

1 substantially helical or spiral scroll over a length
2 of the passage, the nozzle aperture being formed in
3 the wall of the passage.

4
5 A cowl (not shown) may be provided downstream of the
6 exit 5 from the passage 3 in order to further
7 control the mist. The cowl may comprise a number of
8 separate sections arranged in the radial direction,
9 each section controlling and re-directing a portion
10 of the mist spray emerging from the exit 5 of the
11 mist generator 1.

12
13 With reference to Fig. 8, the mist generator 1 is
14 disposed centrally within a cowl or casing 50. The
15 casing 50 comprises a diverging inlet portion 52
16 having an inlet opening 54, a central portion 56 of
17 constant cross-section, leading to a converging
18 outlet portion 58, the outlet portion 58 having an
19 outlet opening 60. Although Fig. 8 illustrates use
20 of the mist generator 1 of Fig. 1 disposed centrally
21 within the casing 50, it is envisaged that any of
22 the embodiments of the present invention may also be
23 used instead.

24
25 In use the inlet opening 54 and the outlet opening
26 60 are in fluid communication with a body of the
27 working fluid either therewithin or connected to a
28 conduit.

29
30 In operation the working fluid is drawn through the
31 casing 50 (by shocks and momentum transfer), or is
32 pumped in by external means, with flow being induced

1 around the housing 2 and also through the passage 3
2 of the mist generator 1.

3
4 The convergent portion 58 of the casing 50 provides
5 a means of enhancing a momentum transfer (suction)
6 in mixing between the flow exiting the mist
7 generator 1 at exit 5 and the fluid drawn through
8 the casing 50. The enhanced suction and mixing of
9 the mist with the fluid drawn through the casing 50
10 could be used in such applications as gas cooling,
11 decontamination and gas scrubbing.

12
13 As an alternative to this specific configuration
14 shown in Fig. 8, inlet portion 52 may display a
15 shallow angle or indeed may be dimensionally
16 coincident with the bore of the central portion 56.
17 The outlet portion 58 may be of varied shape which
18 has different accelerative and mixing performance on
19 the characteristics of the mist plume.

20
21 Fig. 9 shows an alternative embodiment to the
22 previous embodiments, whereby the mist generator 1
23 includes a working nozzle 34 for the introduction of
24 the working fluid (water) into the mixing chamber.
25 In this respect, an inlet fluid, which may be any
26 flowable fluid, can be introduced into the passage 3
27 through the inlet 4. For example, the inlet fluid
28 may be air.

29
30 However, it is anticipated that the working fluid
31 may still be introduced into the mixing chamber via
32 the inlet 4, where a second working fluid may be

1 introduced into the mixing chamber via the working
2 nozzle.

3

4 The working nozzle 34 is in fluid communication with
5 a plenum 32 and a working fluid feed port 30. The
6 working nozzle 34 is located downstream of the
7 transport nozzle 16 nearer to the exit 5, although
8 the working nozzle 34 may be located upstream of the
9 transport nozzle nearer to the inlet 4. The working
10 nozzle 34 is annular and circumscribes the passage
11 3.

12

13 The working nozzle 34 corresponds with the shape of
14 the passage 3 and/or the transport nozzle 16 and
15 thus, for example, a circular passage would
16 advantageously be provided with an annular working
17 nozzle circumscribing said passage.

18

19 However, it is to be appreciated that the working
20 nozzle 34 need not be annular, or indeed, need not
21 be a nozzle. The second nozzle 34 need only be an
22 inlet to allow a working fluid to be introduced into
23 the mixing chamber 3A.

24

25 In the case of a rectilinear passage, which may have
26 a large width to height ratio, working nozzles would
27 be provided at least on each transverse wall, but
28 not necessarily on the sidewalls, although the
29 invention optionally contemplates a full
30 circumscription of the passage by the working
31 nozzles irrespective of shape.

32

1 The working nozzle 34 may be used for the
2 introduction of gases or liquids or of other
3 additives that may, for example, be treatment
4 substances for the working fluid or may be
5 particulates in powder or pulverant form to be mixed
6 with the working fluid. For example, water and an
7 additive may be introduced together via a working
8 nozzle (or separately via two working nozzles). The
9 working fluid and additive are entrained into the
10 mist generator by the low pressure created within
11 the unit (mixing chamber). The fluids or additives
12 may also be pressurised by an external means and
13 pumped into the mist generator, if required.

14
15 For fire fighting applications, typically the
16 working fluid is water, but may be any flowable
17 fluid or mixture of flowable fluids requiring to be
18 dispersed into a mist, e.g. any non-flammable liquid
19 or flowable fluid (inert gas) which absorbs heat
20 when it vaporises may be used instead of, or in
21 addition to via a second working nozzle, the water.

22
23 The working nozzle 34 may be located as close as
24 possible to the projected surface of the transport
25 fluid issuing from the transport nozzle 16. In
26 practice and in this respect a knife edge separation
27 between the transport fluid stream and the working
28 fluid stream issuing from their respective nozzles
29 may be of advantage in order to achieve the
30 requisite degree of interaction of said fluids. The
31 angular orientation of the transport nozzle 16 with

1 respect to the stream of the working fluid is of
2 importance.

3
4 The transport nozzle 16 is conveniently angled
5 towards the stream of working fluid issuing from the
6 second nozzle 34 since this occasions penetration of
7 the working fluid. The angular orientation of both
8 nozzles is selected for optimum performance to
9 enhance turbulence, which is dependent inter alia on
10 the nozzle orientation and the internal geometry of
11 the mixing chamber, to achieve a desired droplet
12 formation (i.e. size, distribution, spray cone angle
13 and projection). Moreover, the creation of
14 turbulence, governed inter alia by the angular
15 orientation of the nozzles, is important to achieve
16 optimum performance by dispersal of the working
17 fluid in order to increase acceleration by momentum
18 transfer and mass transfer.

19
20 Simply put, the more turbulence there is generated,
21 the smaller the droplet size achievable.

22
23 Figs. 10 to 12 show schematics of different
24 configurations of the transport and working nozzles,
25 which provide different degrees of turbulence.

26
27 Fig. 10 shows over expanded transport nozzle. The
28 transport nozzle can be configured to provide a
29 particular steam pressure gradient across it. One
30 parameter that can be changed/controlled is the
31 degree of expansion of the steam through the nozzle.
32 Different steam exit pressures provide different

1 steam exit velocities and temperatures with a
2 subsequent effect on the droplet formation of the
3 mist.

4

5 With an over expanded nozzle the steam exiting the
6 transport nozzle is over expanded such that its
7 local pressure is less than local atmospheric
8 pressure. For example, typical pressures are 0.7 to
9 0.8 bar absolute, with a subsequent steam
10 temperature of approximately 85°C.

11

12 This results in the formation of very weak shocks in
13 the flow. The advantages of this arrangement is
14 that the steam velocity is high, therefore there is
15 a very high primary and secondary break up, which
16 results in relatively smaller droplets. It can also
17 be quieter in operation than other nozzle
18 arrangements (as will be discussed), due to the lack
19 of strong shocks.

20

21 There is a trade-off though in that there is reduced
22 suction pressure created within the mist generator
23 due to the lack of condensation shocks. However,
24 this feature is only desired to entrain the process
25 or working fluid through the mist generator rather
26 than pumping it in.

27

28 Fig. 11 shows an under expanded transport nozzle.
29 With under expanded nozzles the exit steam pressure
30 is higher than local atmospheric pressure, for
31 example it can be approximately 1.2 bar absolute, at
32 a temperature of approximately 115°C. This results

1 in local expansion and condensation shocks. A
2 higher temperature differential between the steam
3 and water can exist, therefore local condensation
4 shocks are generated. This results in a higher
5 suction pressure being generated through the mist
6 generator for the entrainment of the working fluid
7 and inlet fluid.

8
9 However, there is a trade-off in that an under
10 expanded nozzle has a lower steam velocity,
11 resulting in a less efficient primary and secondary
12 break up, leading to slightly larger droplet sizes.

13
14 Fig. 12 shows a largely over expanded transport
15 nozzle. This alternative arrangement has a typical
16 exit pressure of approximately 0.2 bar absolute.
17 However, the exit velocity can be very high,
18 typically approximately 1500m/s (approximately Mach
19 3). This high velocity results in the generation of
20 a very strong localised aerodynamic shock (normal
21 shock) at the steam exit. This shock is so strong
22 that theoretically downstream of the shock the
23 pressure increases to approximately 1.2bar absolute
24 and rises to a temperature of approximately 120°C.
25 This higher temperature may help to reduce the
26 surface tension of the water, so helping to reduce
27 the droplet size. This resultant higher temperature
28 can be used in applications where heat treatment of
29 the working and/or inlet fluid is required, such as
30 the treatment of bacteria.

31

1 However, the trade-off with this arrangement is that
2 the strong shocks reduce the velocity of the steam,
3 therefore there is a reduced effect on the high
4 shear droplet break up mechanism. In addition, it
5 may be noisy.

6
7 Fig. 13 shows a schematic of the interaction of the
8 working and transport flows as they issue from their
9 respective nozzles. Current thinking suggest that
10 optimum performance is achieved when the length of
11 the mixing chamber is limited to the point where the
12 increasing thickness boundary layer between the
13 steam and the water touches the inner surface of the
14 housing 2. Keeping the mixing chamber short like
15 this also allows air to be entrained at the exit 5
16 from the outside surface of the mist generator,
17 where the entrained air increases the mixing and
18 turbulence intensity, and therefore droplet
19 formation. In other words, the intensity of the
20 turbulence allows for the generation of smaller
21 working fluid droplets, which have a relatively
22 increased cooling rate compared with larger droplet
23 sizes.

24
25 In operation the inlet 4 is connected to a source of
26 inlet fluid which is introduced into the inlet 4 and
27 passage 3. The working fluid, water, is introduced
28 into a feed port 30, where the water flows into the
29 plenum 32, and out through the transport nozzle 34.
30 The transport fluid, steam, is introduced into the
31 feed port 10, where the steam flows into the plenum

1 8, and out through the transport nozzle 16 as a high
2 velocity steam jet.

3
4 The high velocity steam jet issuing from the
5 transport nozzle 16 impacts with the water stream
6 issuing from the nozzle 34 with high shear forces,
7 thus atomising the water breaking it into fine
8 droplets and producing a well mixed three-phase
9 condition constituted by the liquid phase of the
10 water, the steam and the air. In this instance, the
11 energy transfer mechanism of momentum and mass
12 transfer occasion's induction of the water through
13 the mixing chamber 3A and out of the exit 5. Mass
14 transfer will generally only occur for hot transport
15 fluids, such as steam.

16
17 As with the previous embodiment, the atomisation
18 mechanisms involved are substantially similar and
19 likewise, the properties or parameters of the inlet,
20 working and transport fluids can be regulated or
21 controlled or manipulated to give the required
22 intensity of shearing and hence, a mist comprising a
23 substantially uniform droplet distribution, a
24 substantial portion of which have a size less than
25 20µm.

26
27 Whilst the nozzles 16, 34 are shown in Fig. 9 as
28 being directed towards the exit 5, it is also
29 envisaged that the working nozzle 34 may be
30 directed/angled towards the inlet 4, which may
31 result in greater turbulence. Also, the working
32 nozzle 34 may be provided at any angle up to 180

1 degrees relative to the transport nozzle in order to
2 produce greater turbulence by virtue of the higher
3 shear associated with the increasing slip velocities
4 between the transport and working fluids. For
5 example, the working nozzle may be provided
6 perpendicular to the transport nozzle.

7
8 In some embodiments of the present invention a
9 series of transport fluid nozzles is provided
10 lengthwise of the passage 3 and the geometry of the
11 nozzles may vary from one to the other dependent
12 upon the effect desired. For example, the angular
13 orientation may vary one to the other. The nozzles
14 may have differing geometries to afford different
15 effects, i.e. different performance characteristics,
16 with possibly differing parametric transport
17 conditions. For example some nozzles may be
18 operated for the purpose of initial mixing of
19 different liquids and gasses whereas other nozzles
20 are used simultaneously for additional droplet break
21 up or flow directionalisation. Each nozzle may have
22 a mixing chamber section downstream thereof. In the
23 case where a series of nozzles are provided, the
24 number of transport nozzles and working fluid
25 nozzles is optional.

26
27 Fig. 14 shows an embodiment of the present invention
28 substantially similar to that shown in Fig. 9 save
29 that the mist generator 1 is provided with a
30 diverging mixing chamber section 3A, and the angular
31 orientation (β) of the nozzles 16, 34 have been
32 adjusted and angled to provide the desired

1 interaction between the steam (transport fluid) and
2 the water (working fluid) occasioning the optimum
3 energy transfer by momentum and mass transfer to
4 enhance turbulence.

5

6 This embodiment operates in substantially the same
7 way as previous embodiments save that this
8 embodiment provides a more diffuse or wider spray
9 cone angle and therefore a wider discharge of mist
10 coverage. Angled walls 36 of the mixing chamber 3A
11 may be angled at different divergent and convergent
12 angles to provide different spray cone angles and
13 discharge of mist coverage.

14

15 Referring now to Fig. 15, which shows an embodiment
16 of the present invention substantially similar to
17 that illustrated in Fig. 14 save that an additional
18 transport fluid feed port 40 and plenum 42 are
19 provided in housing 2, together with a second
20 transport nozzle 44 formed at a location downstream
21 of the second nozzle 34 nearer to the exit 5.

22

23 The second transport nozzle 44 is used to introduce
24 the transport fluid (steam) into the mixing chamber
25 3A downstream of the working fluid (water). The
26 second transport nozzle may be used to introduce a
27 second transport fluid.

28

29 In this embodiment the three nozzles 16, 34, 44 are
30 located coincident with one another thus providing a
31 co-annular nozzle arrangement.

32

1 This embodiment is provided with a diverging mixing
2 chamber section 3A and the nozzles 16, 34, 44 are
3 angled to provide the desired angles of interaction
4 between the two streams of steam and the water, thus
5 occasioning the optimum energy transfer by momentum
6 and mass transfer to enhance turbulence. This
7 arrangement illustrated provides a more diffuse or
8 wider spray cone angle and therefore a wider
9 discharge of mist coverage. The angle of the walls
10 36 of the mixing chamber 3A may be varied
11 convergent-divergent to provide different spray cone
12 angles.

13
14 In operation two high velocity streams of steam exit
15 their respective nozzles 16, 44, and sandwich the
16 water stream issuing from the second nozzle 34.
17 This embodiment both enhances the droplet formation
18 by providing a double shearing action, and also
19 provides a fluid separation or cushion between the
20 water and the walls 36 of the mixing chamber 3A,
21 thus preventing small water droplets being lost
22 through coalescence on the angled walls 36 of the
23 mixing chamber 3A before exiting the mist generator
24 1 via the exit 5. In alternative embodiments, not
25 shown, the mixing chamber section 3A of Figs. 15 and
26 16 may be converging. This will provide a greater
27 exit velocity for the discharge of mist and
28 therefore a greater projection range.

29
30 In a further embodiment of the present invention, as
31 shown in Fig. 16, there is no straight-through
32 passage 3 as with previous embodiments. Thus there

1 is no requirement for the introduction of the inlet
2 fluid.

3
4 In this embodiment the apparatus for generating a
5 mist (mist generator 1) comprises a conduit or
6 housing 2, providing a mixing chamber 9, a transport
7 fluid inlet 3, a working fluid inlet 4 and an outlet
8 or exit 5.

9
10 The transport fluid inlet 3 has an annular chamber
11 or plenum 8 provided in the housing 2, the inlet 3
12 also has an annular transport nozzle 16 for the
13 introduction of a transport fluid into the mixing
14 chamber 9.

15
16 A protrusion 6 extends into the housing 2 and
17 defines a plenum 8 for the introduction of the
18 transport fluid into the mixing chamber 9 via the
19 transport nozzle 16.

20
21 A distal end 12 of the protrusion 6 is tapered on
22 its relatively outer surface 14 and defines the
23 transport nozzle 16 between it and a correspondingly
24 tapered part 18 of the housing 2.

25
26 The working fluid inlet 30 has a plenum 32 provided
27 in the housing 2, the working fluid inlet 30 also
28 has a working nozzle 34 formed at a location
29 coincident with that of the transport nozzle 16.

30

1 The transport nozzle 16 and working nozzle 34 are
2 substantially similar to that of previous
3 embodiments.

4
5 In operation the working fluid inlet 30 is connected
6 to a source of working fluid, water. The transport
7 fluid inlet 3 is connected to a source of transport
8 fluid, steam. Introduction of the steam into the
9 inlet 3, through the plenum 8, causes a jet of steam
10 to issue forth through the transport nozzle 16. The
11 parametric characteristics or properties of the
12 steam, for example, pressure, temperature, dryness,
13 etc., are selected whereby in use the steam issues
14 from the transport nozzle 16 at supersonic speeds
15 into a mixing region of the chamber 10, hereinafter
16 described as the mixing chamber 9. The steam jet
17 issuing from the transport nozzle 16 impacts the
18 working fluid issuing from the second nozzle 34 with
19 high shear forces, thus atomising the water into
20 droplets and occasioning induction of the resulting
21 water mist through the mixing chamber 9 towards the
22 exit 5.

23
24 The parametric characteristics, i.e. the internal
25 geometries of the nozzles 16, 34 and their angular
26 orientation, the cross-section (and length) of the
27 mixing chamber, and the properties of the working
28 and transport fluids are modulated/manipulated to
29 discharge a mist with a substantially uniform
30 droplet distribution having a substantial portion of
31 droplets with a size less than 20 μ m.

32

1 Fig. 17 shows a further embodiment similar to that
2 illustrated in Fig. 16 save that the protrusion 6
3 incorporates a supplementary nozzle 22, which is
4 axial to the longitudinal axis of the housing 2 and
5 which is in fluid communication with the mixing
6 chamber 9. An inlet 3a is formed at a front end of
7 the protrusion 6 (distal from the exit 5) extending
8 into the housing 2 incorporating interiorly thereof
9 a plenum 7 for the introduction of the transport
10 fluid, steam. The plenum 7 is in fluid
11 communication with the plenum 8 through one or more
12 channels 11.

13
14 A distal end 12 of the protrusion 6 remote from the
15 inlet 3A is tapered on its internal surface 20 and
16 defines a parallel axis aligned supplementary nozzle
17 22, the supplementary nozzle 22 being in fluid
18 communication with the plenum 7.

19
20 The supplementary nozzle 22 is so shaped as in use
21 to give supersonic flow of the transport fluid into
22 the mixing chamber 9. For a given steam condition,
23 i.e. dryness (quality), pressure and temperature,
24 the nozzle 22 is preferably configured to provide
25 the highest velocity steam jet, the lowest pressure
26 drop and the highest enthalpy between the plenum and
27 the nozzle exit. However, it is envisaged that the
28 flow of transport fluid into the mixing chamber may
29 alternatively be sub-sonic as hereinbefore
30 described.

31

1 The supplementary nozzle 22 has an area ratio in the
2 range 1.75 to 15 with an included angle (α) less
3 than 6 degrees for supersonic flow, and 12 degrees
4 for sub-sonic flow; although (α) may be higher.

5

6 It is to be appreciated that the supplementary
7 nozzle 22 is angled to provide the desired
8 interaction between the transport and working fluid
9 occasioning the optimum energy transfer by momentum
10 and mass transfer to obtain the required intensity
11 of shearing suitable for the required droplet size.
12 The supplementary nozzle 22 as shown in Fig. 17 may
13 be located off-centre and/or may be tilted.

14

15 In operation the working fluid inlet 30 is connected
16 to a source of the working fluid to be dispersed,
17 water. The transport fluid inlet 3a is connected to
18 a source of transport fluid, steam. Introduction of
19 the steam into the inlet 3a, through the plenums 7,
20 8 causes a jet of steam to issue forth through the
21 transport nozzle 16 and the supplementary nozzle 22.
22 The parametric characteristics or properties of the
23 steam are selected whereby in use the steam issues
24 from the nozzles at supersonic speeds into the
25 mixing chamber 9. The steam jet issuing from the
26 nozzles 16, 22 impact the working fluid issuing from
27 the working nozzle 34 with high shear forces, thus
28 atomising the water into droplets and occasioning
29 induction of the resulting water mist through the
30 mixing chamber 9 towards the exit 5.

31

1 Alternatively, the supplementary nozzle may be
2 connected to a source of a second transport fluid.

3
4 The parametric characteristics, i.e. the internal
5 geometries of the nozzles 16, 34 and their angular
6 orientation, the cross-section (and length) of the
7 mixing chamber, and the properties of the working
8 and transport fluids are modulated/manipulated to
9 discharge a mist having substantially uniform
10 droplet distribution having a substantial portion of
11 droplets with a size less than 20 μ m.

12
13 It is to be appreciated that the supplementary
14 nozzle 22 will increase the turbulent break up, and
15 also influence the shape of the emerging mist plume.

16
17 The supplementary nozzle 22 may be incorporated into
18 any embodiment of the present invention.

19
20 Fig. 18 shows an embodiment substantially similar to
21 that illustrated in Fig. 17 save that an additional
22 transport fluid inlet 40 and plenum 42 are provided
23 in the housing 2, together with a second transport
24 nozzle 44 formed at a location coincident with that
25 of the working nozzle 34, thus providing a co-
26 annular nozzle arrangement.

27
28 The third nozzle 34 is substantially similar to the
29 transport nozzle 16 save for the angular
30 orientation.

31

1 The transport nozzles 16, 44, the supplementary
2 nozzle 22 and the working nozzle 34 are angled to
3 provide the desired angles of interaction between
4 the steam and water, and optimum energy transfer by
5 momentum and mass transfer to enhance turbulence.

6
7 In operation the high velocity steam jets issuing
8 from the nozzles 16, 22, 44 impact the water with
9 high shear forces, thus breaking the water into fine
10 droplets and producing a well mixed two phase
11 condition constituted by the liquid phase of the
12 water, and the steam. This both enhances the
13 droplet formation by providing a double shearing
14 action, and also provides a fluid separation or
15 cushion between the water and the internal walls 36
16 of the mixing chamber 9. This prevents small water
17 droplets being lost through coalescence on the
18 internal walls 36 of the mixing chamber 9 before
19 exiting the mist generator 1 view the outlet 5.
20 Additionally the nozzles 16, 22, 44 are angled and
21 shaped to provide the desired droplet formation. In
22 this instance, the energy transfer mechanism of
23 momentum and mass transfer occasion's projection of
24 the spray mist through the mixing chamber 9 and out
25 of the exit 5.

26
27 Fig. 19 shows an embodiment substantially similar to
28 that illustrated in Fig. 17 save that it is provided
29 with a diverging mixing chamber 9 and a radial
30 transport fluid inlet 3 rather than the parallel
31 axis inlet 3a shown in Fig. 17. However, either
32 inlet type may be used.

1
2 The transport nozzle 16, the supplementary nozzle 22
3 and the working nozzle 34 are angled to provide the
4 desired angles of interaction between the transport
5 and the working fluid occasioning the optimum energy
6 transfer by momentum and mass transfer to enhance
7 turbulence.

8
9 The arrangement illustrated provides a more diffuse
10 or wider spray cone angle and therefore a wider mist
11 coverage. The angle of the internal walls 36 of the
12 mixing chamber 9 relative to a longitudinal
13 centreline of the mist generator 1, and the angles
14 of the nozzles 16 ,22, 34 relative to the walls 36,
15 may be varied to provide different droplet sizes,
16 droplet distributions, spray cone angles and
17 projection ranges. In an alternative embodiment,
18 not shown, the mixing chamber 9 may be converging.
19 This will provide a narrow concentrated mist plume,
20 and may provide a greater axial velocity for the
21 plume and therefore a greater projection range.

22
23 Fig. 20 shows a further embodiment of the present
24 invention substantially similar to the embodiment
25 illustrated in Fig. 19 save that an additional
26 transport fluid inlet 40 and plenum 42 are provided
27 in the housing 2, together with a second transport
28 nozzle 44 formed at a location coincident with that
29 of the working nozzle 34, thus providing a co-
30 annular nozzle arrangement.

31

1 This embodiment is provided with a diverging mixing
2 chamber section 9 and nozzles 16, 22, 34, 44 are
3 also angled to provide the desired angles of
4 interaction between the transport and working fluid,
5 thus occasioning the optimum energy transfer by
6 momentum and mass transfer to enhance turbulence.

7
8 The arrangement illustrated provides a more diffuse
9 or wider spray cone angle and therefore a wider mist
10 coverage. The angle of the inner walls 36 of the
11 mixing chamber 9 relative to the longitudinal
12 centreline of the mist generator 1, and the angles
13 of the nozzles 16, 22, 34, 44 relative to the walls
14 36, may be varied to provide different droplet
15 sizes, droplet distributions, spray cone angles and
16 projection ranges. In an alternative embodiment,
17 not shown, the mixing chamber 9 may be converging.
18 This will provide a narrow concentrated plume, and
19 may provide a greater axial velocity for the plume
20 and therefore a greater projection range.

21
22 In operation the high velocity streams of steam
23 exiting their respective nozzles 16, 22, 44,
24 sandwich the water stream exiting the fluid nozzle
25 34. This both enhances the droplet formation by
26 providing a double shearing action, and also
27 provides a fluid separation or cushion between the
28 water and the walls 36 of the mixing chamber 9.
29 This prevents small water droplets being lost
30 through coalescence on the internal walls of the
31 mixing chamber 9 before exiting the mist generator
32 via the exit 5.

1
2 Referring now to Fig. 21 which shows a further
3 embodiment of an apparatus for generating a mist
4 (mist generator 1) comprising a conduit or housing
5 2, a transport fluid inlet 3a and plenum 7 provided
6 in the housing 2 for the introduction of the
7 transport fluid, steam, into a mixing chamber 9.
8 The mist generator 1 also comprises a protrusion 38
9 at the end of the plenum 7 which is tapered on its
10 relatively outer surface 40 and defines an annular
11 transport nozzle 16 between it and a correspondingly
12 tapered part 18 of the inner wall of the housing 2,
13 the nozzle 16 being in fluid communication with the
14 plenum 7.

15
16 The mist generator 1 includes a working fluid inlet
17 30 and plenum 32 provided in the housing 2, together
18 with a working nozzle 34 formed at a location
19 coincident with that of the transport nozzle 16.

20
21 This embodiment is provided with a diverging mixing
22 chamber section 9 and the transport nozzle 16 and
23 the working nozzle 34 are also angled to provide the
24 desired angles of interaction between the transport
25 and working fluid, thus occasioning the optimum
26 energy transfer by momentum and mass transfer to
27 enhance turbulence. The arrangement illustrated
28 provides a diffuse or wide spray cone angle and
29 therefore a wider plume coverage. The angle of the
30 internal walls 36 of the mixing chamber 9 relative
31 to the longitudinal centreline of the mist generator
32 1, and the angles of the nozzles 16, 34 relative to

1 the walls 36, may be varied to provide different
2 droplet sizes, droplet distributions, spray cone
3 angles and projection ranges. In an alternative
4 embodiment, not shown, the mixing chamber 9 may be
5 converging. This provides a narrow concentrated
6 plume, a greater axial velocity for the plume and
7 therefore a greater projection range.

8
9 Fig. 22 shows a further embodiment substantially
10 similar to that illustrated in Fig. 21 save that the
11 protrusion 38 incorporates a parallel axis aligned
12 supplementary nozzle 22, the nozzle 22 being in flow
13 communication with a plenum 7.

14
15 The supplementary nozzle 22 is substantially similar
16 to previous supplementary nozzles.

17
18 In operation the working fluid inlet 30 is connected
19 to a source of working fluid, water. The inlet 3a
20 is connected to a source of transport fluid, steam.
21 Introduction of the steam into the inlet 3a, through
22 the plenum 7 causes jets of steam to issue forth
23 through the transport nozzles 16, 22. The
24 parametric characteristics or properties of the
25 steam are selected whereby in use the steam issues
26 from the nozzles 16, 22 at supersonic speeds into
27 the mixing chamber 9. The steam jet issuing from
28 the nozzle 16 impacts the working fluid issuing from
29 the working nozzle 34 with high shear forces, thus
30 atomising the water into droplets and occasioning
31 induction of the resulting water mist through the
32 mixing chamber 9 towards an exit 5. The angle of

1 the walls 36 of the mixing chamber 9 relative to the
2 longitudinal centreline of the mist generator 1, and
3 the angles of the nozzles 16, 22, 34 relative to the
4 walls 36, may be varied to provide different droplet
5 sizes, spray cone angles and projection ranges.

6
7 Fig. 23 is a graph showing the distribution of
8 droplet diameters achieved [A] by percentage volume
9 in a test of an apparatus according to the present
10 invention, along with the associated cumulative
11 distribution percentage [B]. The measurement was
12 taken at a distance of 10m from the exit of the
13 apparatus, and at an angle of 5 degrees off a
14 longitudinal centre-line of the apparatus. The
15 total combined water and steam flow rate was
16 25.6kg/min.

17
18 The droplet diameters achieved [A] show a
19 substantial portion of droplets (cumulative
20 distribution [B] in excess of 95%) with a size less
21 than 10 μ m. The droplet diameters achieved [A] also
22 have a tight uniform distribution between 4 and 6 μ m.
23 This is a particular advantage of the present
24 invention in that a substantially uniform droplet
25 distribution having a substantial portion of
26 droplets with a size less than 20 μ m can be achieved.
27 Also, such droplets have sufficient momentum to
28 project a sufficient distance and also penetrate
29 into the heat of a fire.

30
31 In tests, the apparatus according to the present
32 invention was configured to give the following

1 technical data: mist output=25Kg/min, droplet
2 size= $D_v 0.9 < 10 \mu\text{m}$, projection=20m, exit
3 velocity=12m/s, exit temperature at 2m= an ambient
4 atmospheric temperature of 15°C, steam
5 requirements=8kg/min, water/chemical
6 entrainment=17kg/min, volume flux at 10m= 2.71×10^{-8}
7 $\text{m}^3/(\text{m}^2 \text{ s})$, water surface area=500 m^2/s , droplet
8 production= 6.3×10^{12} /sec.
9

10 It is to be appreciated that any feature or
11 derivative of the embodiments shown in Figs. 1 to 22
12 may be adopted or combined with one another to form
13 other embodiments.
14

15 It is also to be appreciated that whilst the
16 supplementary nozzles have been described in fluid
17 communication with the transport fluid, it is
18 anticipated that the supplementary nozzles may be
19 connected to a second transport fluid.
20

21 It is an advantage of the present invention that the
22 working nozzle(s) provides an annular flow having an
23 even distribution of working fluid around the
24 annulus.
25

26 With reference to the aforementioned embodiments of
27 the present invention, the parametric
28 characteristics or properties of the inlet, working
29 and transport fluids, for example the flow rate,
30 pressure, velocity, quality and temperature, can be
31 regulated to give the required intensity of shearing
32 and droplet formation. The properties of the inlet,

1 working and transport fluids being controllable by
2 either external means, such as a pressure regulation
3 means, or by the gap size (internal geometry)
4 employed within the nozzles.

5
6 Although Figs. 17, 18, 21, 22 illustrate the
7 transport fluid inlet 3a located in a parallel axis
8 to the longitudinal centreline of the mist generator
9 1, feeding transport fluid directly into plenum 7,
10 it is envisaged that the transport fluid may be
11 introduced through alternative locations, for
12 example through a radial inlet such as inlet 3 as
13 illustrated in Fig. 19, which in turn may feed
14 either or both plenums 7 and 8 directly, or through
15 an alternative parallel axis location feeding
16 directly into plenum 8 rather than plenum 7 (not
17 shown). Additionally the fluid inlet 30 may
18 alternatively be positioned in a parallel axis
19 location (not shown), feeding working fluid along
20 the housing to the plenum 32.

21
22 In all embodiments of the present invention, the
23 working nozzles may alternatively form the inlet for
24 other fluids, or solids in flowable form such as a
25 powder, to be dispersed for use in mixing or
26 treatment purposes. For example, a further working
27 fluid inlet nozzle may be provided to provide
28 chemical treatment of the working fluid, such as a
29 fire retardant, if necessary. The placement of the
30 second working nozzle may be either upstream or
31 downstream of the transport nozzle or where more
32 than one transport nozzle is provided, the placement

1 may be both upstream and downstream dependent upon
2 requirements.

3

4 For using the mist generator as a fire suppressant
5 in a room or other contained volume, the mist
6 generator 1 may be either located entirely within
7 the volume or room containing a fire, or located
8 such that only the exit 5 protrudes into the volume.
9 Consequently, the inlet fluid entering via inlet 4
10 may either be the gasses already within the room,
11 these may range from cold gasses to hot products of
12 combustion, or may be a separate fluid supply, for
13 example air or an inert gas from outside the room.
14 In the situation where the mist generator 1 is
15 located entirely within the room, the induced flow
16 through the passage 3 of the mist generator 1 may
17 induce smoke and other hot combustion products to be
18 drawn into the inlet 4 and be intimately mixed with
19 the other fluids within the mist generator. This
20 will increase the wetting and effect on these gases
21 and particles. It is also to be appreciated that
22 the actual mist will increase the wetting and
23 cooling effect on the gasses and particles too.

24

25 Generating and introducing a mist containing a large
26 amount of air into a potentially explosive
27 environment such as a combustible gas filled room
28 will result in both the reduction of risk of
29 ignition from the mist plus the dilution of the gas
30 to a safe gas/oxygen ratio from the air.

31

1 If a fire in a contained volume has burnt most of
2 the available oxygen, a water mist may be introduced
3 but with the flow of air stopped. This helps to
4 extinguish the remaining fire without the risk of
5 adding more oxygen. To this end, the flow of the
6 inlet fluid (air) through the inlet 4 may be
7 controllable by restricting or even closing the
8 inlet 4 completely. This could be accomplished by
9 using a control valve. Alternatively, the
10 embodiments shown in Figs. 16 to 22 may be used in
11 this scenario.

12
13 In a modification, an inert gas may be used as the
14 inlet fluid in place of air, or, with regard to
15 using the embodiments shown in Figs. 16 to 22, a
16 further working nozzle may be added to introduce an
17 inert gas or non-flammable fluid to suppress the
18 fire.

19
20 Similarly, powders or other particles may be
21 entrained or introduced into the mist generator,
22 mixed with and dispersed with another fluid or
23 fluids. The particles being dispersed with the
24 other fluid or fluids, or wetted and/or coated or
25 otherwise treated prior to being projected.

26
27 The mist generator of the present invention has a
28 number of fundamental advantages over conventional
29 water mist systems in that the mechanism of droplet
30 formation and size is controlled by a number of
31 adjustable parameters, for example, the flow rate,
32 pressure, velocity, quality and temperature of the

1 inlet, transport and working fluid; the angular
2 orientation and internal geometry of the transport,
3 supplementary and working nozzles; the cross-
4 sectional area and length of the mixing chamber 3A.
5 This provides active control over the amount of
6 water used, the droplet size, the droplet
7 distribution, the spray cone angle and the projected
8 range (distance) of the mist.
9

10 A key advantage of the present invention is that it
11 generates a substantially uniform droplet
12 distribution, a substantial portion of which have a
13 size less than $20\mu\text{m}$ that have sufficient momentum,
14 because of the momentum transfer, to project a
15 sufficient distance and also penetrate into the heat
16 of a fire, which is distinct with the prior art
17 where droplet sizes less than $40\mu\text{m}$ will have
18 insufficient momentum to project a sufficient
19 distance and also penetrate into the heat of a fire.
20

21 A major advantage of the present invention is its
22 ability to handle relatively more viscous working
23 fluids and inlet fluids than conventional systems.
24 The shocks and the momentum transfer that takes
25 place provide suction causing the mist generator to
26 act like a pump. Also, the shearing effect and
27 turbulence of the high velocity steam jet breaks up
28 the viscous working fluid and mixes it, making it
29 less viscous.
30

1 conditions, i.e. flow rate, pressure, velocity,
2 temperature, etc., and the water flow rate
3 conditions, i.e. flow rate, pressure, velocity, and
4 temperature, and the inlet fluid conditions.
5

6 Droplet formation within the mist generator may be
7 further enhanced with the entrainment of chemicals
8 such as surfactants. The surfactants can be
9 entrained directly into the mist generator and
10 intimately mixed with the working fluid at the point
11 of droplet formation, thereby minimising the
12 quantity of surfactant required.
13

14 It is an advantage of the straight-through passage
15 of the mist generator, and the relatively large
16 inlet nozzle geometries, that it can accommodate
17 material that might find its way into the passage.
18 It is a feature of the present invention that it is
19 far more tolerant of the water quality used than
20 conventional systems which depend on small orifices
21 and closely toleranced nozzles.
22

23 The ability of the mist generator to handle and
24 process a range of working fluids provides
25 advantages over many other mist generator. As the
26 desired droplet size is achieved through high
27 velocity shear and, in the case of steam as the
28 transport fluid, mass transfer from a separate
29 transport fluid, almost any working fluid can be
30 introduced to the mist generator to be finely
31 dispersed and projected. The working fluids can
32 range from low viscosity easily flowable fluids and

1 fluid/solid mixtures to high viscosity fluids and
2 slurries. Even fluids or slurries containing
3 relatively large solid particles can be handled.

4
5 It is this versatility that allows the present
6 invention to be applied in many different
7 applications over a wide range of operating
8 conditions. Furthermore the shape of the mist
9 generator may be of any convenient form suitable for
10 the particular application. Thus the mist generator
11 may be circular, curvilinear or rectilinear, to
12 facilitate matching of the mist generator to the
13 specific application or size scaling.

14
15 The present invention thus affords wide
16 applicability with improved performance over the
17 prior art proposals in the field of mist generator.

18
19 In some embodiments of the present invention a
20 series of transport nozzles and working nozzles is
21 provided lengthwise of the passage and the geometry
22 of the nozzles may vary from one to the other
23 dependent upon the effect desired. For example, the
24 angular orientation may vary one to the other. The
25 nozzles may have differing geometries in order to
26 afford different effects, i.e. different performance
27 characteristics, with possibly differing parametric
28 steam conditions. For example, some nozzles may be
29 operated for the purpose of initial mixing of
30 different liquids and gases whereas others are used
31 simultaneously for additional droplet break-up or
32 flow directionalisation. Each nozzle may have a

1 mixing chamber section downstream thereof. In the
2 case where a series of nozzles is provided the
3 number of operational nozzles is variable.

4

5 The mist generator of the present invention may be
6 employed in a variety of applications ranging from
7 fire extinguishing, suppression or control to smoke
8 or particle wetting.

9

10 Due to the relatively low pressures involved in the
11 present invention, the mist generator can be easily
12 relocated and re-directed while in operation. Using
13 appropriate flexible steam and water supply pipes
14 the mist generator is easily man portable. The unit
15 can be considered portable from two perspectives.
16 Firstly the transport nozzle(s) can be moved
17 anywhere only constrained by the steam and water
18 pipe lengths. This may have applications for fire
19 fighting or decontamination when the nozzle can be
20 man-handled to specific areas for optimum coverage
21 of the mist. This 'umbilical' approach could be
22 extended to situations where the nozzle is moved by
23 a robotic arm or a mechanised system, being operated
24 remotely. This may have applications in very
25 hazardous environments.

26

27 Secondly, the whole system could be portable, i.e.
28 the nozzle, a steam generator, plus a water/chemical
29 supply is on a movable platform (e.g., self
30 propelled vehicle). This would have the benefits of
31 being unrestricted by any umbilical pipe lengths.

1 The whole system could possibly utilise a back-pack
2 arrangement.

3
4 The present invention may also be used for mixing,
5 dispersion or hydration and again the shearing
6 mechanism provides the mechanism for achieving the
7 desired result. In this connection the mist
8 generator may be used for mixing one or more fluids,
9 one or more fluids and solids in flowable or
10 particulate form, for example powders. The fluids
11 may be in liquid or gaseous form. This mechanism
12 could be used for example in the fighting of forest
13 fires, where powders and other additives, such as
14 fire suppressants, can be entrained, mixed and
15 dispersed with the mist spray.

16
17 In this area of usage lies another potential
18 application in terms of foam generation for fire
19 fighting purposes. The separate fluids, for example
20 water, a foaming agent, and possibly air, are mixed
21 within the mist generator using the transport fluid,
22 for example steam, by virtue of the shearing effect.

23
24 Additionally, in fire or other high temperature
25 environments the high density fine droplet mist
26 generated by the mist generator provides a thermal
27 barrier for people and fuel. In addition to
28 reducing heat transfer by convection and conduction
29 by cooling the air and gasses between the heat
30 source and the people or fuel, the dense mist also
31 reduces heat transfer by radiation. This has
32 particular, but not exclusive, application to fire

1 and smoke suppression in road, rail and air
2 transport, and may greatly enhance passenger post-
3 crash survivability.

4
5 The fine droplet mist generated by the present
6 invention may be employed for general cooling
7 applications. The high cooling rate and low water
8 quantities used provide the mechanism for cooling of
9 industrial machinery and equipment. For example,
10 the fine droplet mist has particular application for
11 direct droplet cooling of gas turbine inlet air.
12 The fine droplet mist, typically a water mist, is
13 introduced into the inlet air of the gas turbine and
14 due to the small droplet size and large evaporative
15 surface area, the water mist evaporates, cooling
16 the inlet air. The cooling of the inlet air boosts
17 the power of the gas turbine when it is operating in
18 hot environments.

19
20 Also, the very fine droplet mist produced by the
21 mist generator may be utilised for cooling and
22 humidifying area or spaces, either indoors or
23 outdoors, for the purpose of providing a more
24 habitable environment for people and animals.

25
26 The mist generator may be employed either indoors or
27 outdoors for general watering applications, for
28 example, the watering of the plants inside a
29 greenhouse. The water droplet size and distribution
30 may be controlled to provide the appropriate
31 watering mechanism, i.e. either root or foliage
32 wetting, or a combination of both. In addition, the

1 humidity of the greenhouse may also be controlled
2 with the use of the mist generator.

3
4 The mist generator may be used in an explosive
5 atmosphere to provide explosion prevention. The
6 mist cools the atmosphere and dampens any airborne
7 particulates, thus reducing the risk of explosion.
8 Additionally, due to the high cooling rate and wide
9 droplet distribution afforded by the fine droplet
10 mist the mist generator may be employed for
11 explosion suppression, particularly in a contained
12 volume.

13
14 A fire within a contained room will generally
15 produce hot gasses which rise to the ceiling. There
16 is therefore a temperature gradient formed with high
17 temperatures at or near the ceiling and lower
18 temperatures towards the floor. In addition, the
19 gasses produced will generally become stratified
20 within the room at different heights. An advantage
21 of the present invention is that the turbulence and
22 projection force of the mist helps to mix the gasses
23 within the room, mixing the high temperature gasses
24 with the low temperature gasses, thus reducing the
25 hot spot temperatures of the room.

26
27 This mixing of the room's gasses, and the turbulent
28 mist itself, which behaves more akin to a gas cloud,
29 is able to reach non line-of-sight areas, so
30 eliminating all hot spots (pockets of hot gasses)
31 and possible re-ignition zones. A further advantage
32 of the present invention is that the smaller water

1 droplets have more of a tendency to remain airborne,
2 thereby cooling the gases and the combustion
3 products of the fire. This improves the rate of
4 cooling of the fire and also reduces damage to items
5 in the vicinity of the fire.

6
7 The turbulence and projection force of the mist
8 allows for substantially all of the surfaces in the
9 room to be cooled, even the non line of sight
10 surfaces.

11
12 In addition, the turbulence and projection force of
13 the mist cause the water droplets to become attached
14 to hygroscopic nuclei suspended in the gasses,
15 causing the nuclei to become heavier and fall to the
16 floor, where they are more manageable; particularly
17 in decontamination applications. The water droplets
18 generated by the present invention have more of a
19 tendency to become attached to the nuclei by virtue
20 of their smaller size.

21
22 The mist generator may be used to deliberately
23 create hygroscopic nuclei within the room for the
24 purpose outlined above.

25
26 Due to the particle wetting of the gasses in a
27 contained volume by the mist generator and the
28 turbulence created within the apparatus and by the
29 cooling mist itself, pockets of gas are dispersed,
30 thereby limiting the chance of explosion.

31

1 The mist generator has a further advantage for use
2 in potentially explosive atmospheres as it has no
3 moving parts or electrical wires or circuitry and
4 therefore has minimum sources of ignition.

5
6 The present invention has the additional benefit of
7 wetting or quenching of explosive or toxic
8 atmospheres utilising either just the steam, or with
9 additional entrained water and/or chemical
10 additives. The later configuration could be used for
11 placing the explosive or toxic substances in
12 solution for safe disposal.

13
14 Using a hot compressible transport fluid, such as
15 steam, may provide an additional advantage of
16 providing control of harmful bacteria. The shearing
17 mechanism afforded by the present invention coupled
18 with the heat input of the steam destroys the
19 bacteria in the fluid flow, thereby providing for
20 the sterilisation of the working fluid. The
21 sterilisation effect could be enhanced further with
22 the entrainment of chemicals or other additives
23 which are mixed into the working fluid. This may
24 have particular advantage in applications such as
25 fire fighting, where the working fluid, such as
26 water, is advantageously required to be stored for
27 some time prior to use. During operation, the mist
28 generator effectively sterilises the water,
29 destroying bacterium such as legionella pneumophila,
30 during the droplet creation phase, prior to the
31 water mist being projected from the mist generator.

32

1 The fine droplet mist produced by the mist generator
2 might be advantageously employed where there has
3 been a leakage or escape of chemical or biological
4 materials in liquid or gaseous form. The atomised
5 spray provides a mist which effectively creates a
6 blanket saturation of the prevailing atmosphere
7 giving a thorough wetting result. In the case where
8 chemical or biological materials are involved, the
9 mist wets the materials and occasions their
10 precipitation or neutralisation, additional
11 treatment could be provided by the introduction or
12 entrainment of chemical or biological additives into
13 the working fluid. For example disinfectants may be
14 entrained or introduced into the mist generator, and
15 introduced into a room to be disinfected in a mist
16 form. For decontamination applications, such as
17 animal decontamination or agricultural
18 decontamination, no premix of the chemicals is
19 required as the chemicals can be entrained directly
20 into the unit and mixed simultaneously. This
21 greatly reduces the time required to start
22 decontamination and also eliminates the requirement
23 for a separate mixer and holding tank.

24
25 The mist generator may be deployed as an extractor
26 whereby the injection of the transport fluid, for
27 example steam, effects induction of a gas for
28 movement from one zone to another. One example of
29 use in this way is to be found in fire fighting when
30 smoke extraction at the scene of a fire is required.

31

1 Further the mist generator may be employed to
2 suppress or dampen down particulates from a gas.
3 This usage has particular, but not exclusive,
4 application to smoke and dust suppression from a
5 fire. Additional chemical additives in fluid and/or
6 powder form may be entrained and mixed with the flow
7 for treatment of the gas and/or particulates.

8
9 Further the mist generator for scrubbing particulate
10 materials from a gas stream, to effect separation of
11 wanted elements from waste elements. Additional
12 chemical additives in fluid and/or powder form may
13 be entrained and mixed with the flow for treatment
14 of the gas and/or particulates. This usage has
15 particular, but not exclusive, application to
16 industrial exhaust scrubbers and dust extraction
17 systems.

18
19 The use of the mist generator is not limited to the
20 creation of water droplet mists. The mist generator
21 may be used in many different applications which
22 require a fluid to be broken down into a fine
23 droplet mist. For example, the mist generator may
24 be used to atomise a fuel, such as fuel oil, for the
25 purpose of enhancing combustion. In this example,
26 using steam as the transport fluid and a liquid fuel
27 as the working fluid produces a finely dispersed
28 mixture of fine fuel droplets and water droplets.
29 It is well known in the art that such mixtures when
30 combined with oxygen provides for enhanced
31 combustion. In this example, the oxygen, possibly
32 in the form of air, could also be entrained, mixed

1 with and projected with the fuel/steam mist by the
2 mist generator. Alternatively, a different
3 transport fluid could be used and water or another
4 fluid can be entrained and mixed with the fuel
5 within the mist generator.

6
7 Alternatively, using a combustible fuel and air as
8 the working fluids, but with a source of ignition at
9 the exit of the unit, the mist generator may be
10 employed as a space heater.

11
12 Further, the mist generator may be employed as an
13 incinerator or process heater. In this example, a
14 combustible fluid, for example propane, may be used
15 as the transport fluid, introduced to the mist
16 generator under pressure. In this example the
17 working fluid may be an additional fuel or material
18 which is required to be incinerated. Interaction
19 between the transport fluid and working fluid
20 creates a well mixed droplet mist which can be
21 ignited and burnt in the mixing chamber or a
22 separate chamber immediately after the exit.

23 Alternatively, the transport fluid can be ignited
24 prior to exiting the transport nozzles, thereby
25 presenting a high velocity and high temperature
26 flame to the working fluid.

27
28 The mist generator affords the ability to create
29 droplets created of a multi fluid emulsion. The
30 droplets may comprise a homogeneous mix of different
31 fluids, or may be formed of a first fluid droplet
32 coated with an outer layer or layers of a second or

1 more fluids. For example, the mist generator may be
2 employed to create a fuel/water emulsion droplet
3 mist for the purpose of further enhancing
4 combustion. In this example, the water may either
5 be separately entrained into the mist generator, or
6 provided by the transport fluid itself, for example
7 from the steam condensing upon contact with the
8 working fluid. Additionally, the oxygen required
9 for combustion, possibly in the form of air, could
10 also be entrained, mixed with and projected with the
11 fuel/steam mist by the generator.

12
13 The mist generator may be employed for low pressure
14 impregnation of porous media. The working fluid or
15 fluids, or fluid and solids mixtures being dispersed
16 and projected onto a porous media, so aiding the
17 impregnation of the working fluid droplets into the
18 material.

19
20 The mist generator may be employed for snow making
21 purposes. This usage has particular but not
22 exclusive application to artificial snow generation
23 for both indoor and outdoor ski slopes. The fine
24 water droplet mist is projected into and through the
25 cold air whereupon the droplets freeze and form a
26 frozen droplet 'snow'. This cooling mechanism may
27 be further enhanced with the use of a separate
28 cooler fitted at the exit of the mist generator to
29 enhance the cooling of the water mist. The
30 parametric conditions of the mist generator and the
31 transport fluid and working fluid properties and
32 temperatures are selected for the particular

1 environmental conditions in which it is to operate.
2 Additional fluids or powders may be entrained and
3 mixed within the mist generator for aiding the
4 droplet cooling and freezing mechanism. A cooler
5 transport fluid than steam could be used.

6
7 The high velocity of the water mist spray may
8 advantageously be employed for cutting holes in
9 compacted snow or ice. In this application the
10 working fluid, which may be water, may
11 advantageously be preheated before introduction to
12 the mist generator to provide a higher temperature
13 droplet mist. The enhanced heat transfer with the
14 impact surface afforded by the water being in a
15 droplet form, combined with the high impact velocity
16 of the droplets provide a melting/cutting through
17 the compacted snow or ice. The resulting waste
18 water from this cutting operation is either driven
19 by the force of the issuing water mist spray back
20 out through the hole that has been cut, or in the
21 case of compacted snow may be driven into the
22 permeable structure of the snow. Alternatively,
23 some or all of the waste water may be introduced
24 back into the mist generator, either by entrainment
25 or by being pumped, to provide or supplement the
26 working fluid supply. The mist generator may be
27 moved towards the 'cutting face' of the holes as the
28 depth of the hole increases. Consequently, the
29 transport fluid and the water may be supplied to the
30 mist generator co-axially, to allow the feed supply
31 pipes to fit within the diameter of the hole
32 generated. The geometry of the nozzles, the mixing

1 chamber and the outlet of the mist generator, plus
2 the properties of the transport fluid and working
3 fluid are selected to produce the required hole size
4 in the snow or ice, and the cutting rate and water
5 removal rate.

6
7 Modifications may be made to the present invention
8 without departing from the scope of the invention,
9 for example, the supplementary nozzle, or other
10 additional nozzles, could be used in the form of
11 NACA ducts, which are used to bleed high pressure
12 from a high pressure surface to a low pressure
13 surface to maintain the boundary layer on the
14 surfaces and reduce drag.

15
16 The NACA ducts may be employed on the mist generator
17 1 from the perspective of using drillings through
18 the housing 2 to feed a fluid to a wall surface
19 flow. For example, additional drillings could be
20 employed to simply feed air or steam through the
21 drillings to increase the turbulence in the mist
22 generator and increase the turbulent break up. The
23 NACA ducts may also be angled in such a way to help
24 directionalise the mist emerging from the mist
25 generator. Holes or even an annular nozzle may be
26 situated on the trailing edge of the mist generator
27 to help to force the exiting mist to continue to
28 expand and therefore diffuse the flow (an exiting
29 high velocity flow will tend to want to converge).

30
31 NACA ducts could be employed, depending on the
32 application, by using the low pressure area within

1 the mist generator to draw in gasses from the
2 outside surface to enhance turbulence. NACA ducts
3 may have applications in situations where it is
4 beneficial to draw in the surrounding gasses to be
5 processed with the mist generator, for example,
6 drawing in hot gasses in a fire suppression role may
7 help to cool the gasses and circulate the gasses
8 within the room.

9
10 Enhancing turbulence in the mist generator helps to
11 both increase droplet formation (with smaller
12 droplets) and also the turbulence of the generated
13 mist. This has benefits in fire suppression and
14 decontamination of helping to force the mist to mix
15 within the mist generator and wet all surfaces
16 and/or mix with the hot gasses. In addition to the
17 aforesaid, turbulence may be induced by the use of
18 guide vanes in either the nozzles or the passage.
19 Turbulators may be helical in form or of any other
20 form which induces swirl in the fluid stream.

21
22 As well as turbulators increasing turbulence, they
23 will also reduce the risk of coalescence of the
24 droplets on the turbulator vanes/blades.

25
26 The turbulators themselves could be of several
27 forms, for example, surface projections into the
28 fluid path, such as small projecting vanes or nodes;
29 surface grooves of various profiles and orientations
30 as shown in Figs 2 to 7; or larger systems which
31 move or turn the whole flow - these may be angled
32 blades across the whole bore of the flow, of either

1 a small axial length or of a longer 'Archimedes type
2 design. In addition, elbows of varying angles
3 positioned along various planes may be used to induce
4 swirl in the flow streams before they enter their
5 respective inlets.

6
7 It is anticipated that the mist generator may
8 include piezoelectric or ultrasonic actuators that
9 vibrate the nozzles to enhance droplet break up.

1 **Claims**

2

3 1. Apparatus for generating a mist comprising:
4 a conduit having a mixing chamber and an exit;
5 a working fluid inlet in fluid communication
6 with said conduit;
7 a transport nozzle in fluid communication with
8 the said conduit, the transport nozzle adapted to
9 introduce a transport fluid into the mixing chamber;
10 the transport nozzle having an angular orientation
11 and internal geometry such that in use the transport
12 fluid interacts with the working fluid introduced
13 into the mixing chamber through the working fluid
14 inlet to atomise and form a dispersed vapour/droplet
15 flow regime, which is discharged as a mist
16 comprising working fluid droplets, a substantial
17 portion of the droplets having a size less than
18 20 μ m.

19

20 2. The apparatus of claim 1, wherein the working
21 fluid droplets have a substantially uniform droplet
22 distribution having droplets with a size less than
23 20 μ m.

24

25 3. The apparatus of claim 1 or 2, wherein the
26 substantial portion of the droplets has a cumulative
27 distribution greater than 90%.

28

29 4. The apparatus of any preceding claim, wherein a
30 substantial portion of the droplets have a droplet
31 size less than 10 μ m

32

1 12. The apparatus of any preceding claim, further
2 including a working nozzle in fluid communication
3 with the conduit for the introduction of working
4 fluid into the mixing chamber.
5

6 13. The apparatus of claim 12, wherein the working
7 nozzle is positioned nearer to the exit than the
8 transport nozzle.
9

10 14. The apparatus of claim 12 or 13, wherein the
11 working nozzle is shaped such that working fluid
12 introduced into the mixing chamber through the
13 working nozzle has a convergent or divergent flow
14 pattern.
15

16 15. The apparatus of any of claims 12 to 14,
17 wherein the working nozzle has inner and outer
18 surfaces each being substantially frustoconical in
19 shape.
20

21 16. The apparatus of any preceding claim, further
22 including a second transport nozzle being adapted to
23 introduce further transport fluid or a second
24 transport fluid into the mixing chamber.
25

26 17. The apparatus of claim 16, wherein the second
27 transport nozzle is positioned nearer to the exit
28 than the transport nozzle.
29

30 18. The apparatus of claim 17, wherein the second
31 transport nozzle is positioned nearer to the exit
32 than the working nozzle, such that the working

1
2 26. The apparatus of any of claims 23 to 25,
3 wherein the supplementary nozzle is shaped with a
4 convergent-divergent profile to provide supersonic
5 flow of the transport fluid which flows
6 therethrough.

7
8 27. The apparatus of any preceding claim, further
9 including control means adapted to control one or
10 more of droplet size, droplet distribution, spray
11 cone angle and projection distance.

12
13 28. The apparatus of any preceding claim, further
14 including control means to control one or more of
15 the flow rate, pressure, velocity, quality, and
16 temperature of the inlet and/or working and/or
17 transport fluids.

18
19 29. The apparatus of claim 27 or 28, wherein the
20 control means includes means to control the angular
21 orientation and internal geometry of the working
22 and/or transport and/or secondary nozzles.

23
24 30. The apparatus of any of claims 27 to 29,
25 wherein the control means includes means to control
26 the internal geometry of at least part of the mixing
27 chamber or exit to vary it between convergent and
28 divergent.

29
30 31. The apparatus of any preceding claim, wherein
31 the exit of the apparatus is provided with a cowl to
32 control the mist.

- 1
- 2 32. The apparatus of claim 31, wherein the cowl
- 3 comprises a plurality of separate sections arranged
- 4 radially, each section adapted to control and re-
- 5 direct a portion of the discharge of mist emerging
- 6 from the exit.
- 7
- 8 33. The apparatus of any preceding claim, wherein
- 9 the apparatus for generating a mist is located
- 10 within a further cowl.
- 11
- 12 34. The apparatus of any preceding claim, wherein
- 13 at least one of the transport, secondary or working
- 14 nozzles is adapted with a turbulator to enhance
- 15 turbulence.
- 16
- 17 35. A spray system comprising apparatus of any of
- 18 claims 1 to 34 and transport fluid in the form of
- 19 steam.
- 20
- 21 36. The spray system of claim 35, further including
- 22 working fluid in the form of water.
- 23
- 24 37. The spray system of claim 35 or 36, further
- 25 including a steam generator and water supply.
- 26
- 27 38. The spray system of claim 37, wherein the spray
- 28 system is portable.
- 29
- 30 39. A method of generating a mist comprising the
- 31 steps of:

1 providing apparatus for generating a mist
2 comprising a transport nozzle and a conduit, the
3 conduit having a mixing chamber and an exit;
4 introducing a stream of transport fluid into
5 the mixing chamber through the transport nozzle;
6 introducing a working fluid into the mixing
7 chamber;
8 atomising the working fluid by interaction of
9 the transport fluid with the working fluid to form a
10 dispersed vapour/droplet flow regime; and
11 discharging the dispersed vapour/droplet flow
12 regime through the exit as a mist comprising working
13 fluid droplets, a substantial portion of the
14 droplets having a size less than 20µm.

15
16 40. The method of claim 39, wherein the apparatus
17 is an apparatus according to any of claims 1 to 38.

18
19 41. The method of claim 39 or 40, wherein the
20 stream of transport fluid introduced into the mixing
21 chamber is annular.

22
23 42. The method of any of claims 39 to 41, wherein
24 the working fluid is introduced into the mixing
25 chamber via an inlet of the mixing chamber of the
26 apparatus.

27
28 43. The method of any of claims 39 to 41, wherein
29 the working fluid is introduced into the mixing
30 chamber via a working nozzle in fluid communication
31 with the conduit of the apparatus.

32

1 44. The method of claim 43, wherein an inlet fluid
2 is introduced into the mixing chamber via an inlet
3 of the mixing chamber of the apparatus.
4

5 45. The method of any of claims 39 to 44, wherein
6 the method includes the step of introducing the
7 transport fluid into the mixing chamber in a
8 continuous or discontinuous or intermittent or
9 pulsed manner.
10

11 46. The method of any of claims 39 to 45, wherein
12 the method includes the step of introducing the
13 transport fluid into the mixing chamber as a
14 supersonic flow.
15

16 47. The method of any of claims 39 to 46, wherein
17 the method includes the step of introducing the
18 transport fluid into the mixing chamber as a sub-
19 sonic flow.
20

21 48. The method of any of claims 39 to 47, wherein
22 the method includes the step of introducing the
23 working fluid into the mixing chamber in a
24 continuous or discontinuous or intermittent or
25 pulsed manner.
26

27 49. The method of any of claims 39 to 48, wherein
28 the mist is controlled by modulating at least one of
29 the following parameters:

30 the flow rate, pressure, velocity, quality
31 and/or temperature of the transport fluid;

1 the flow rate, pressure, velocity, quality
2 and/or temperature of the working fluid;
3 the flow rate, pressure, velocity, quality
4 and/or temperature of the inlet fluid;
5 the angular orientation of the transport and/or
6 working and/or secondary nozzle(s) of the apparatus;
7 the internal geometry of the transport and/or
8 working and/or secondary nozzle(s) of the apparatus;
9 and
10 the internal geometry, length and/or cross
11 section of the mixing chamber.
12

13 50. The method of claim 49, wherein the mist is
14 controlled to have a substantial proportion of its
15 droplets having a size less than 20 μ m.
16

17 51. The method of claim 49, wherein the mist is
18 controlled to have a substantial proportion of its
19 droplets having a size less than 10 μ m.
20

21 52. The method of any of claims 39 to 51, including
22 the generation of condensation shocks and/or
23 momentum transfer to provide suction within the
24 apparatus.
25

26 53. The method of any of claims 39 to 52, including
27 inducing turbulence of the inlet fluid prior to it
28 being introduced into the mixing chamber.
29

30 54. The method of any of claims 39 to 53, including
31 inducing turbulence of the working fluid prior to it
32 being introduced into the mixing chamber.

1

2 55. The method of any of claims 39 to 54, including
3 inducing turbulence of the transport fluid prior to
4 it being introduced into the mixing chamber.

5

6 56. The method of any of claims 39 to 55, wherein
7 the transport fluid is steam or an air/steam
8 mixture.

9

10 57. The method of any of claims 39 to 56, wherein
11 the working fluid is water or a water-based liquid.

12

13 58. The method of any of claims 39 to 57, wherein
14 the mist is used for fire suppression.

15

16 59. The method of any of claims 39 to 58, wherein
17 the mist is used for decontamination.

18

19 60. The method of any of claims 36 to 59, wherein
20 the mist is used for gas scrubbing.

1 Abstract

2
3 The present invention relates to apparatus for
4 generating a mist comprising a conduit having a
5 mixing chamber and an exit; a working fluid inlet in
6 fluid communication with said conduit; a transport
7 nozzle in fluid communication with the said conduit,
8 the transport nozzle adapted to introduce a
9 transport fluid into the mixing chamber; the
10 transport nozzle having an angular orientation and
11 internal geometry such that in use the transport
12 fluid interacts with the working fluid introduced
13 into the mixing chamber through the working fluid
14 inlet to atomise and form a dispersed vapour/droplet
15 flow regime, which is discharged as a mist
16 comprising working fluid droplets, a substantial
17 portion of the droplets having a size less than
18 20 μ m. The present invention also relates to a method
19 of generating a mist comprising the steps of
20 providing apparatus for generating a mist comprising
21 a transport nozzle and a conduit, the conduit having
22 a mixing chamber and an exit; introducing a stream
23 of transport fluid into the mixing chamber through
24 the transport nozzle; introducing a working fluid
25 into the mixing chamber; atomising the working fluid
26 by interaction of the transport fluid with the
27 working fluid to form a dispersed vapour/droplet
28 flow regime; and discharging the dispersed
29 vapour/droplet flow regime through the exit as a
30 mist comprising working fluid droplets, a
31 substantial portion of the droplets having a size
32 less than 20 μ m.



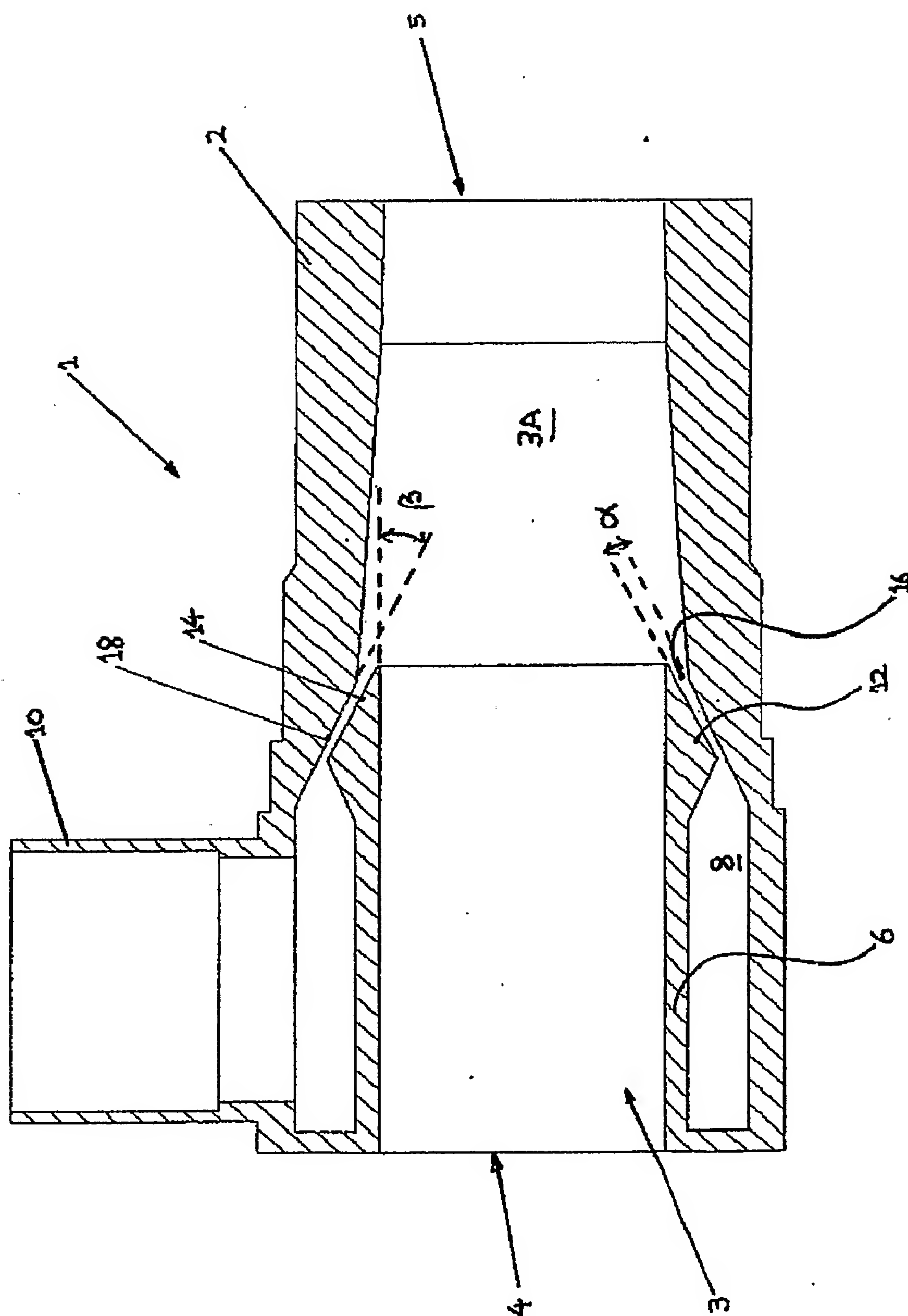
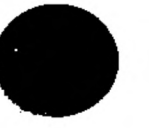


Figure 1



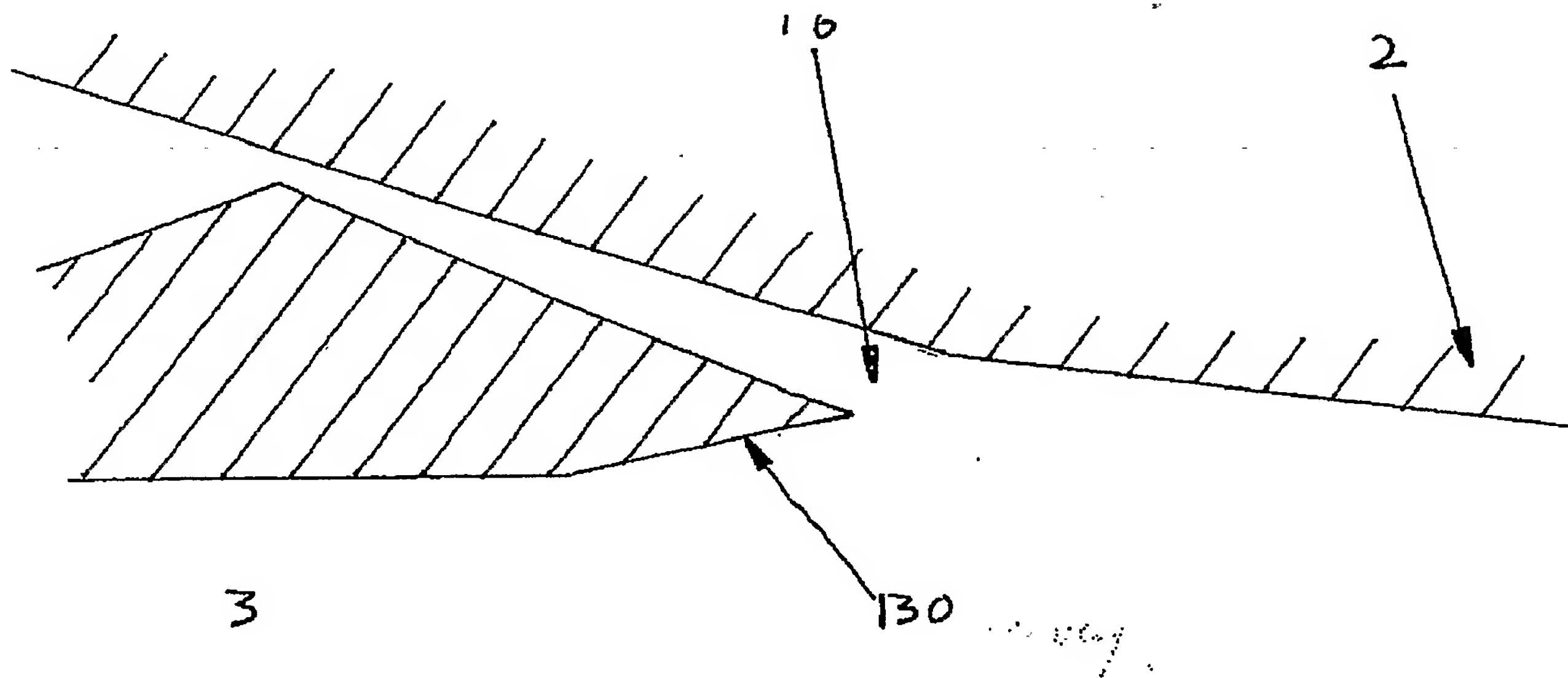


Figure 2

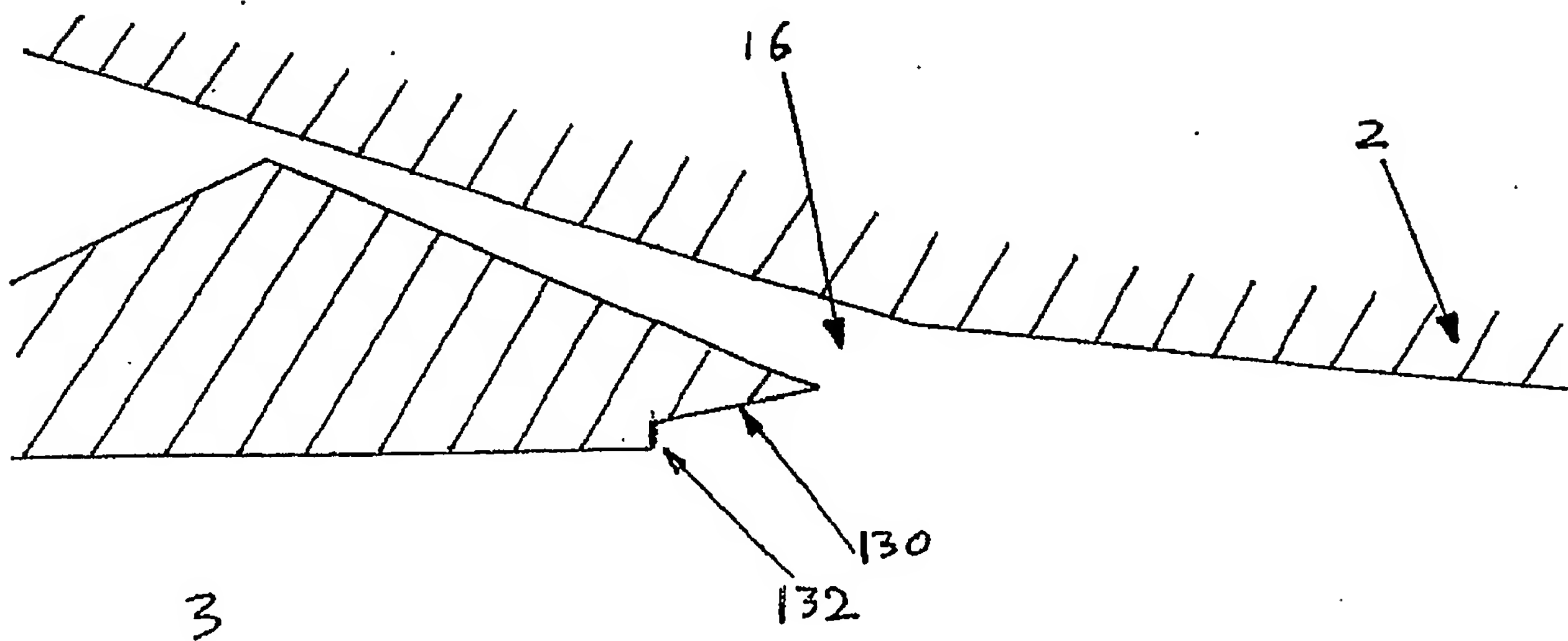


Figure 3



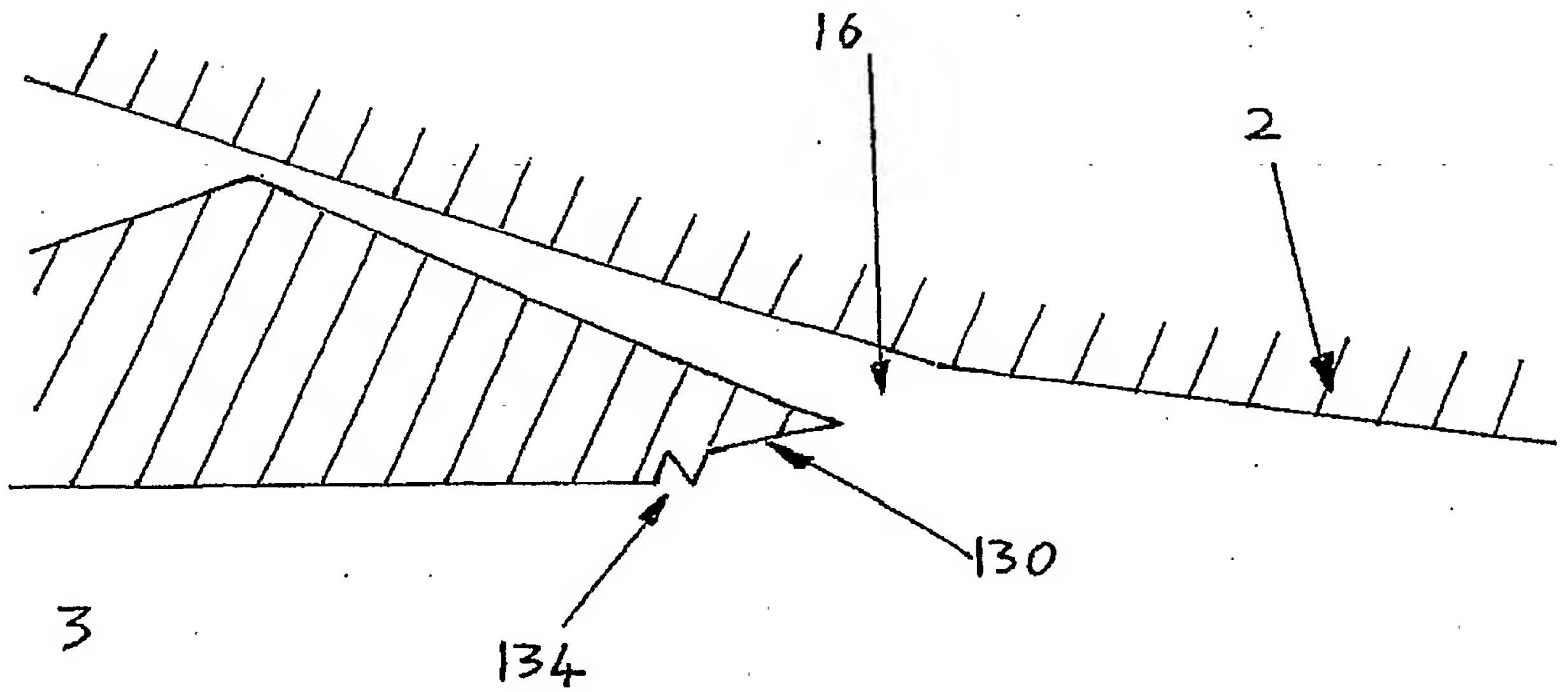


figure 4

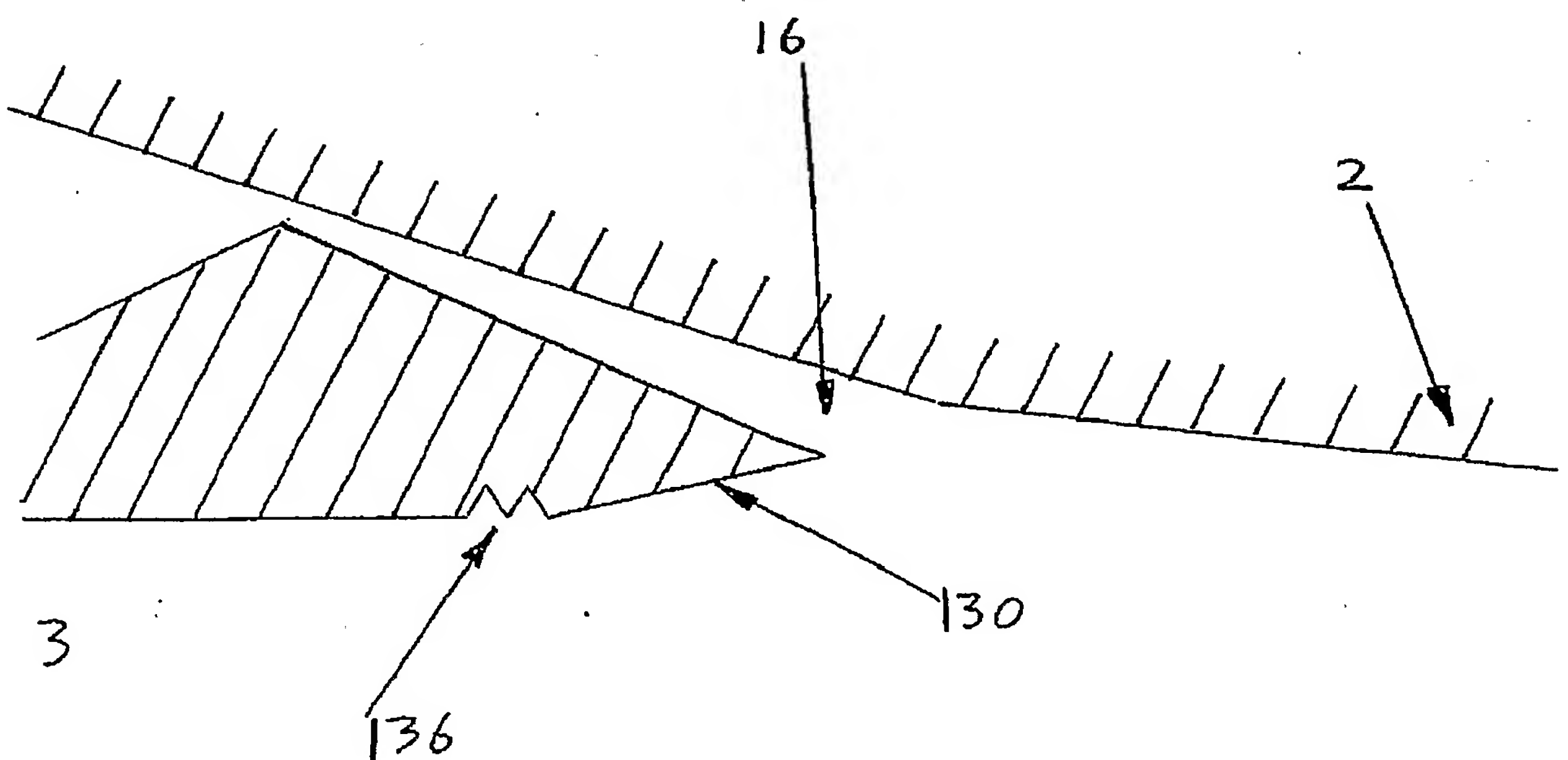


figure 5



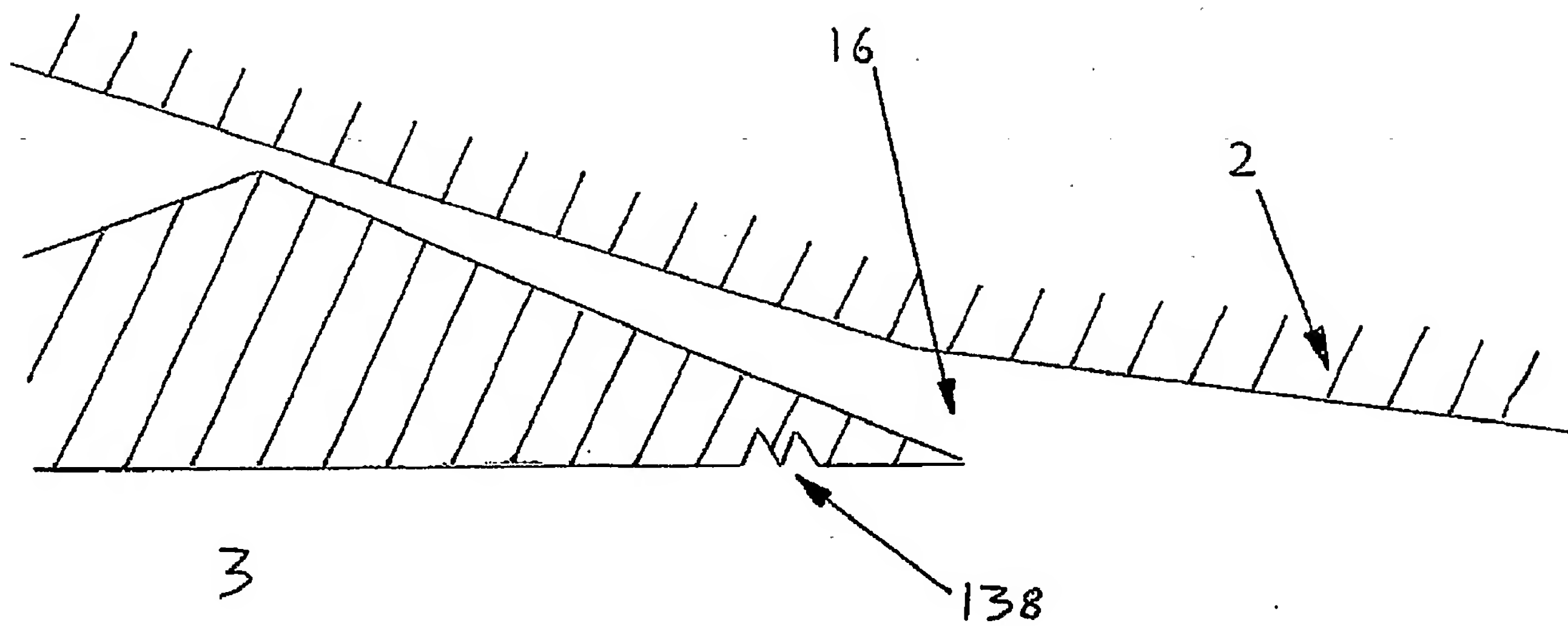


figure 6

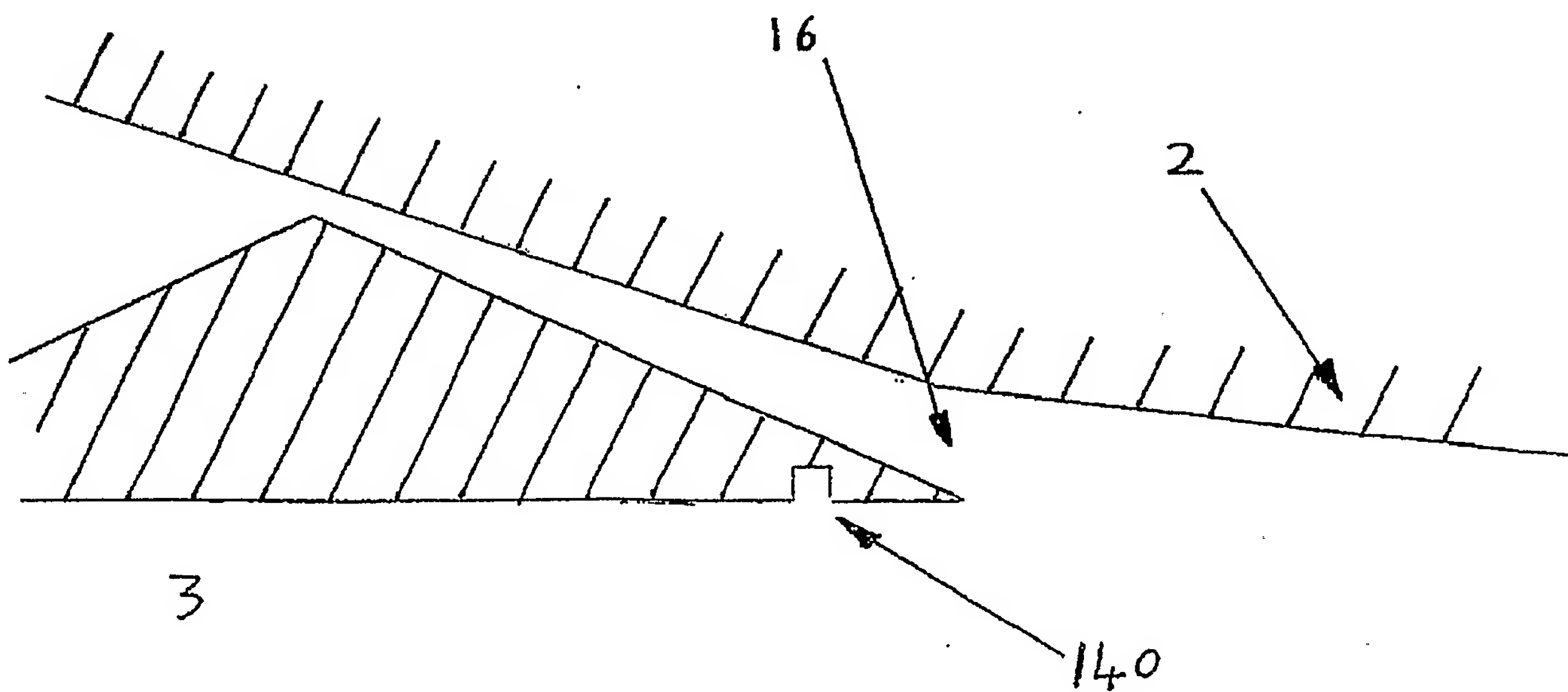
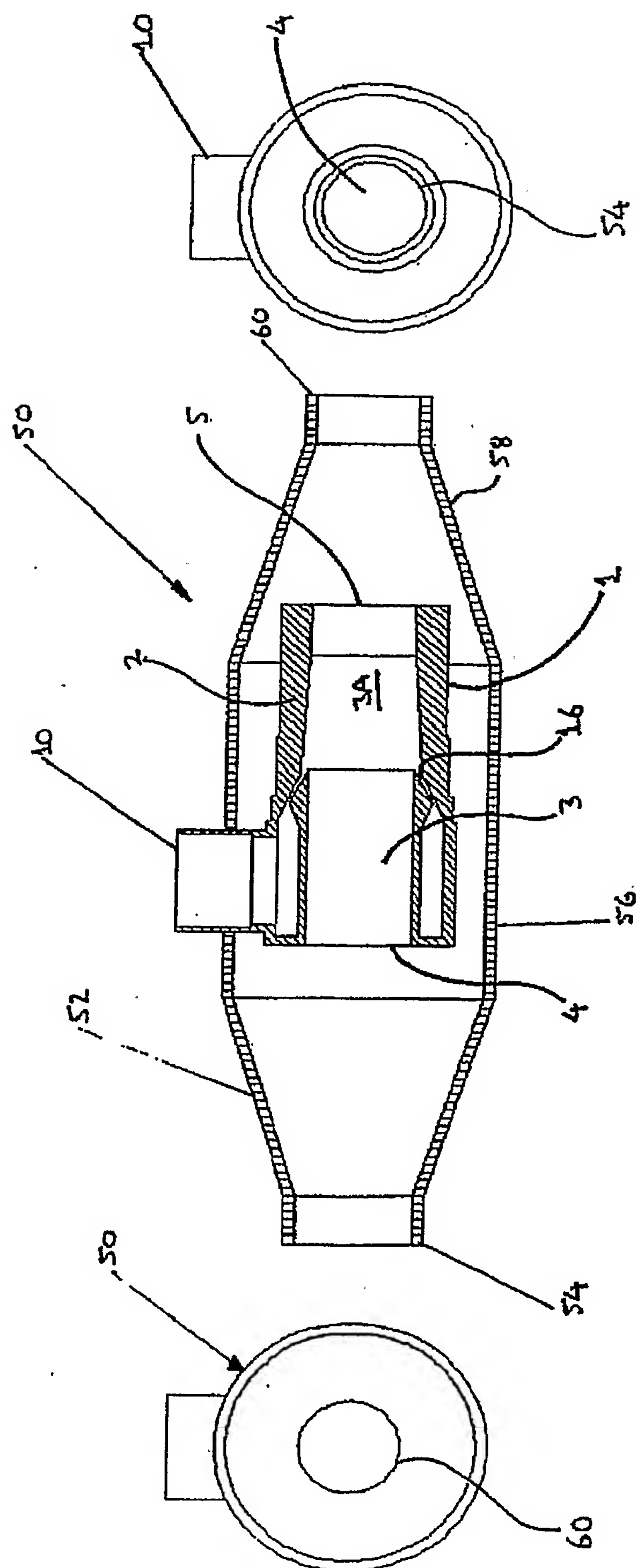


figure 7





Page 8



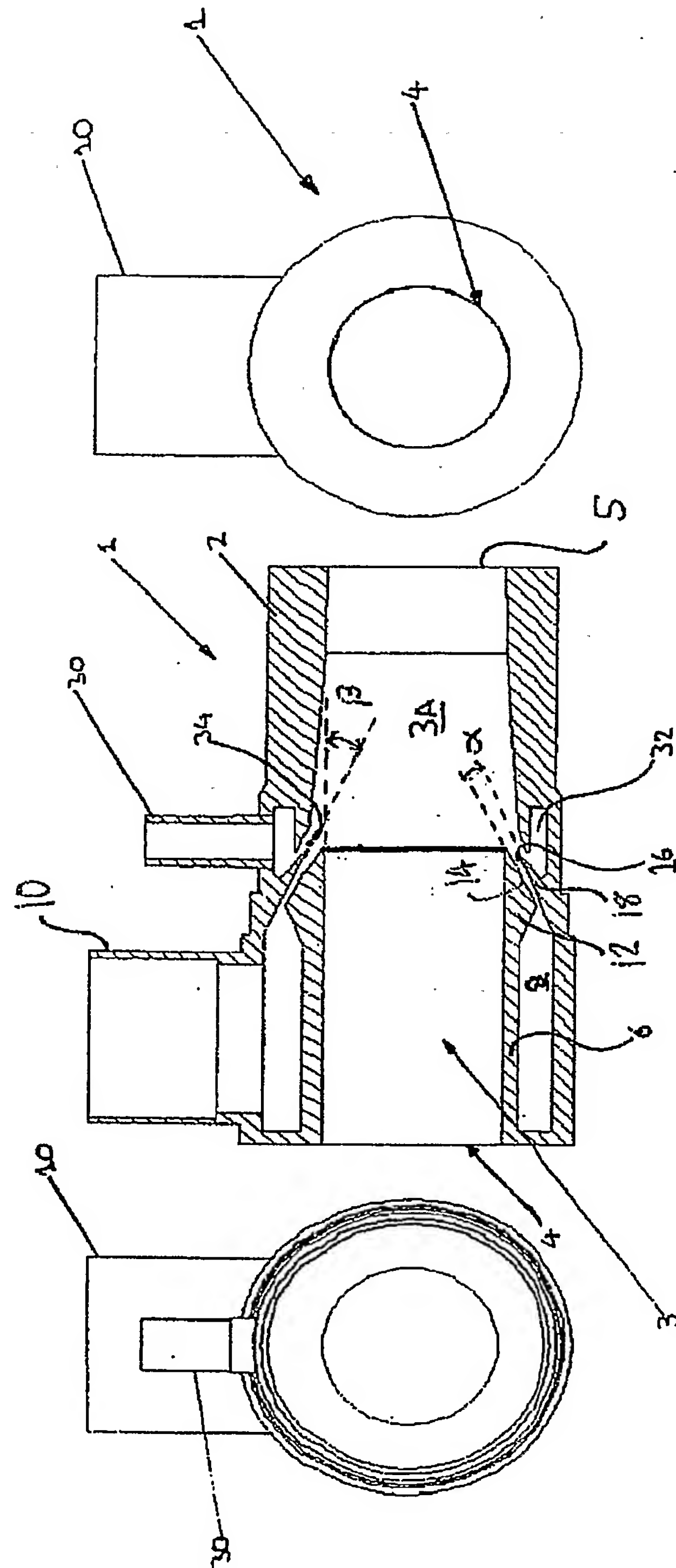
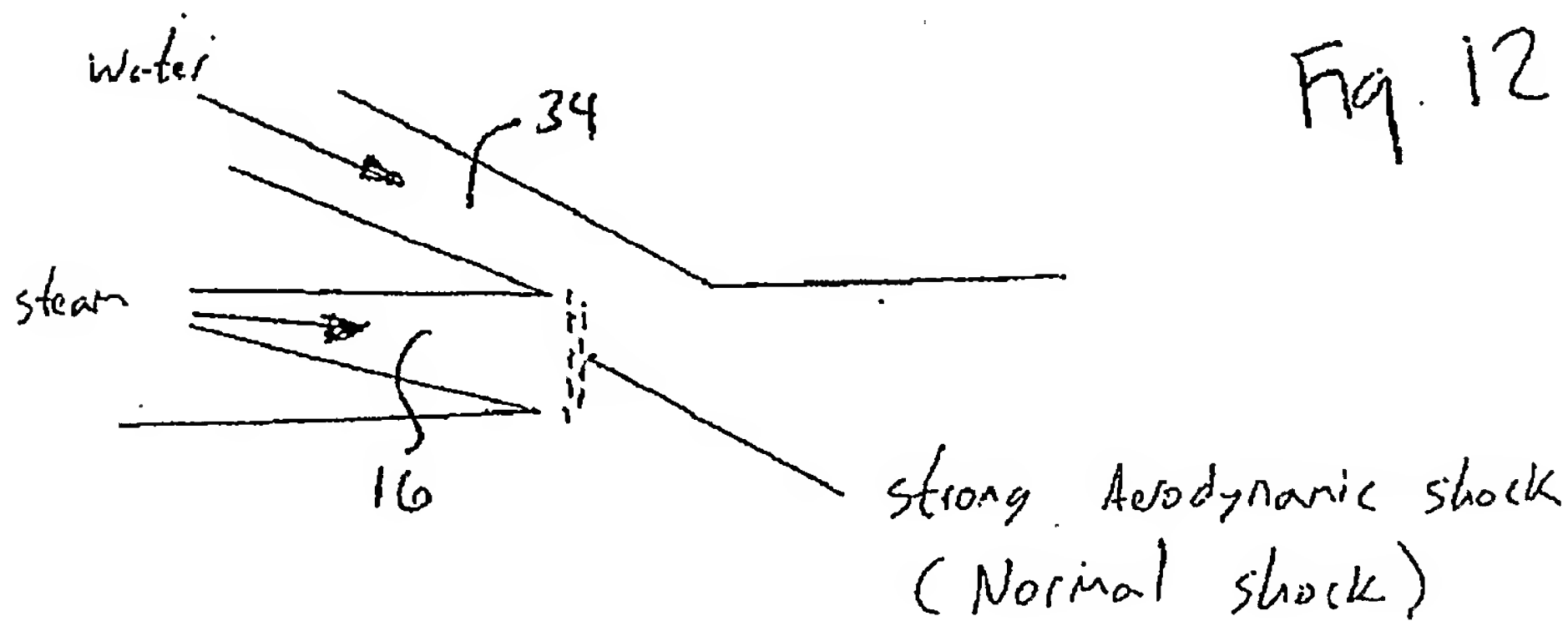
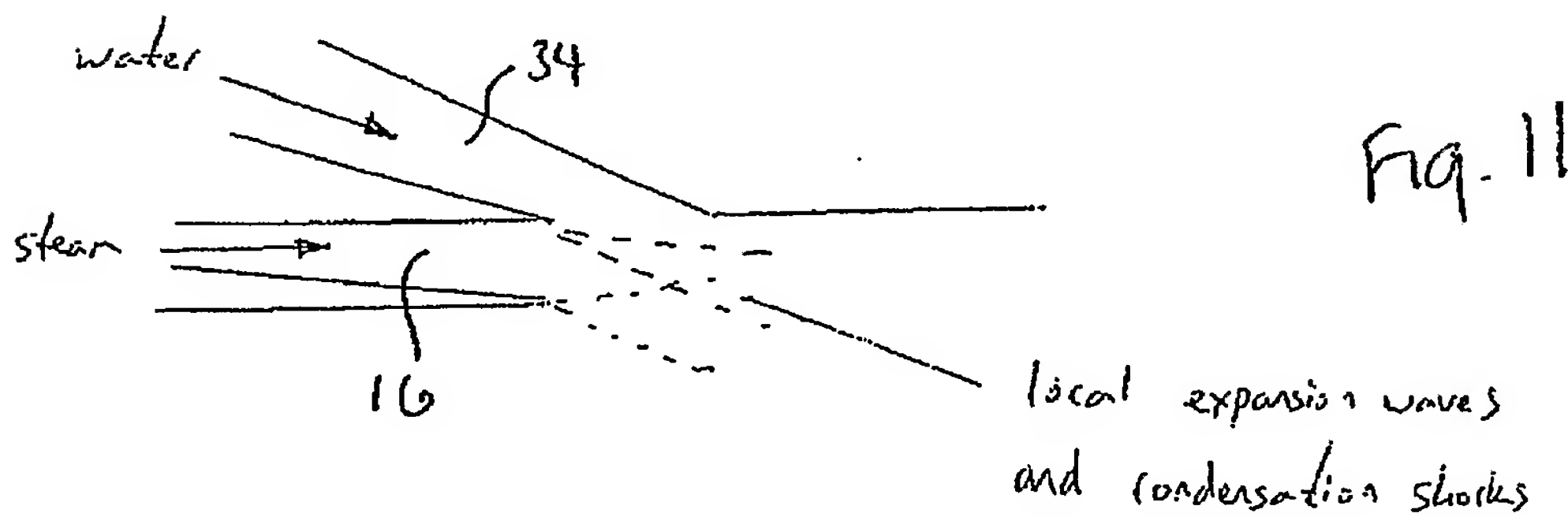
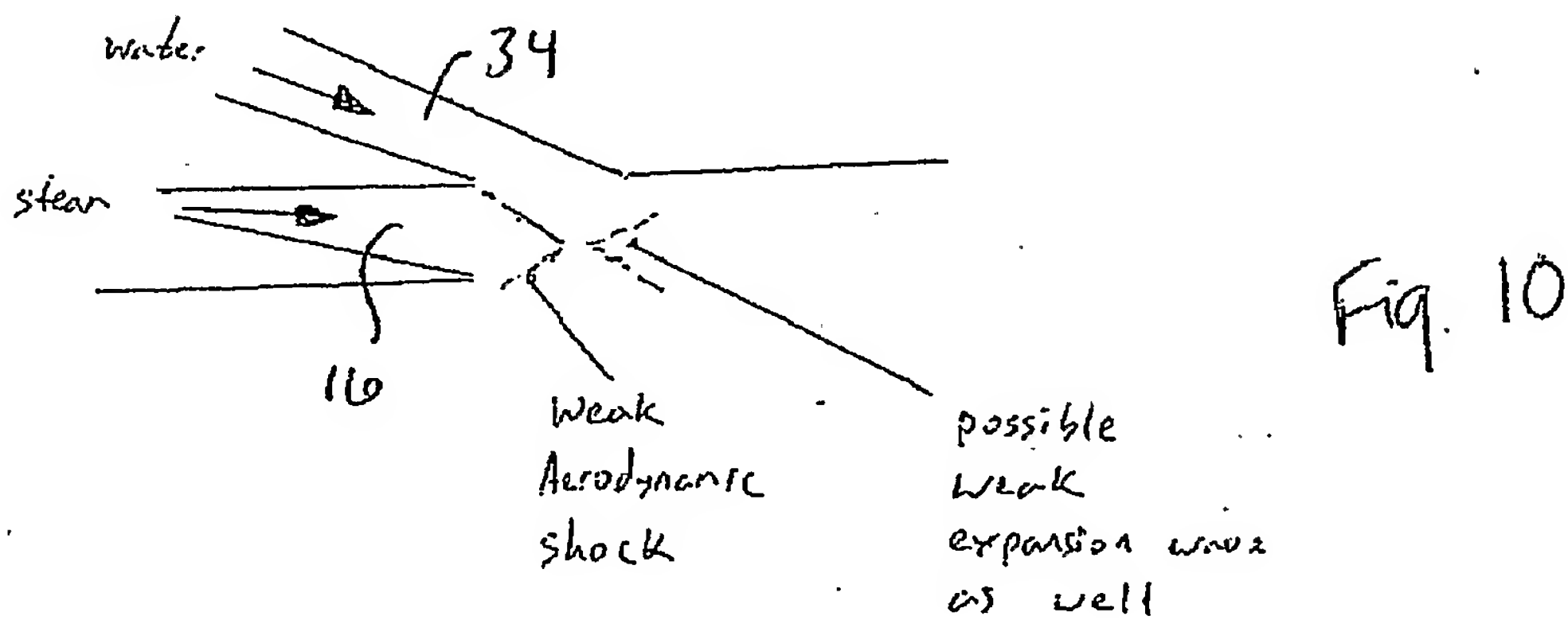
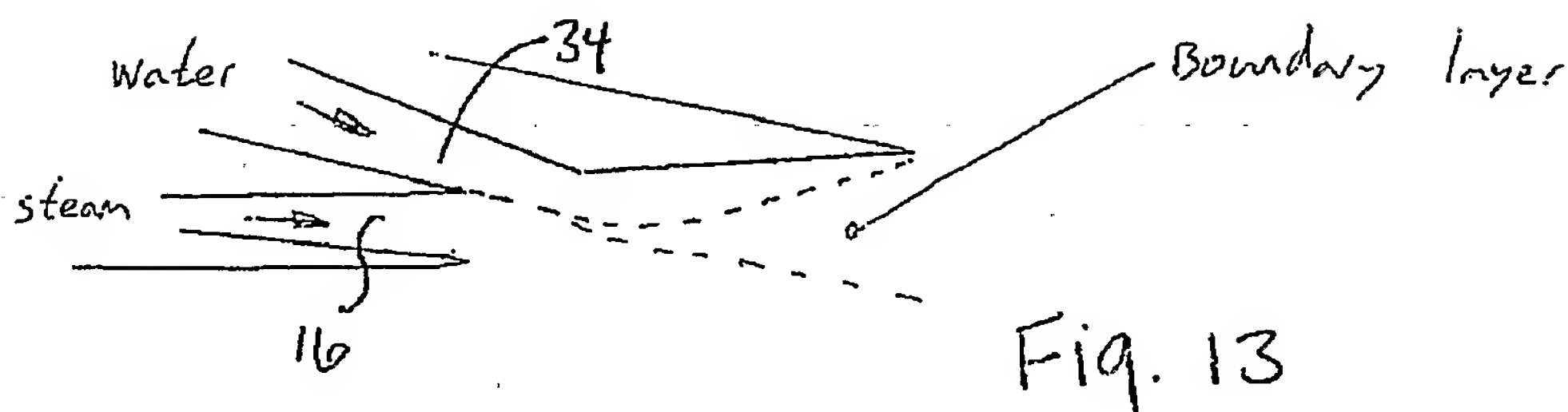
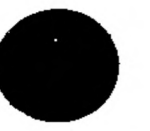


Figure 9:







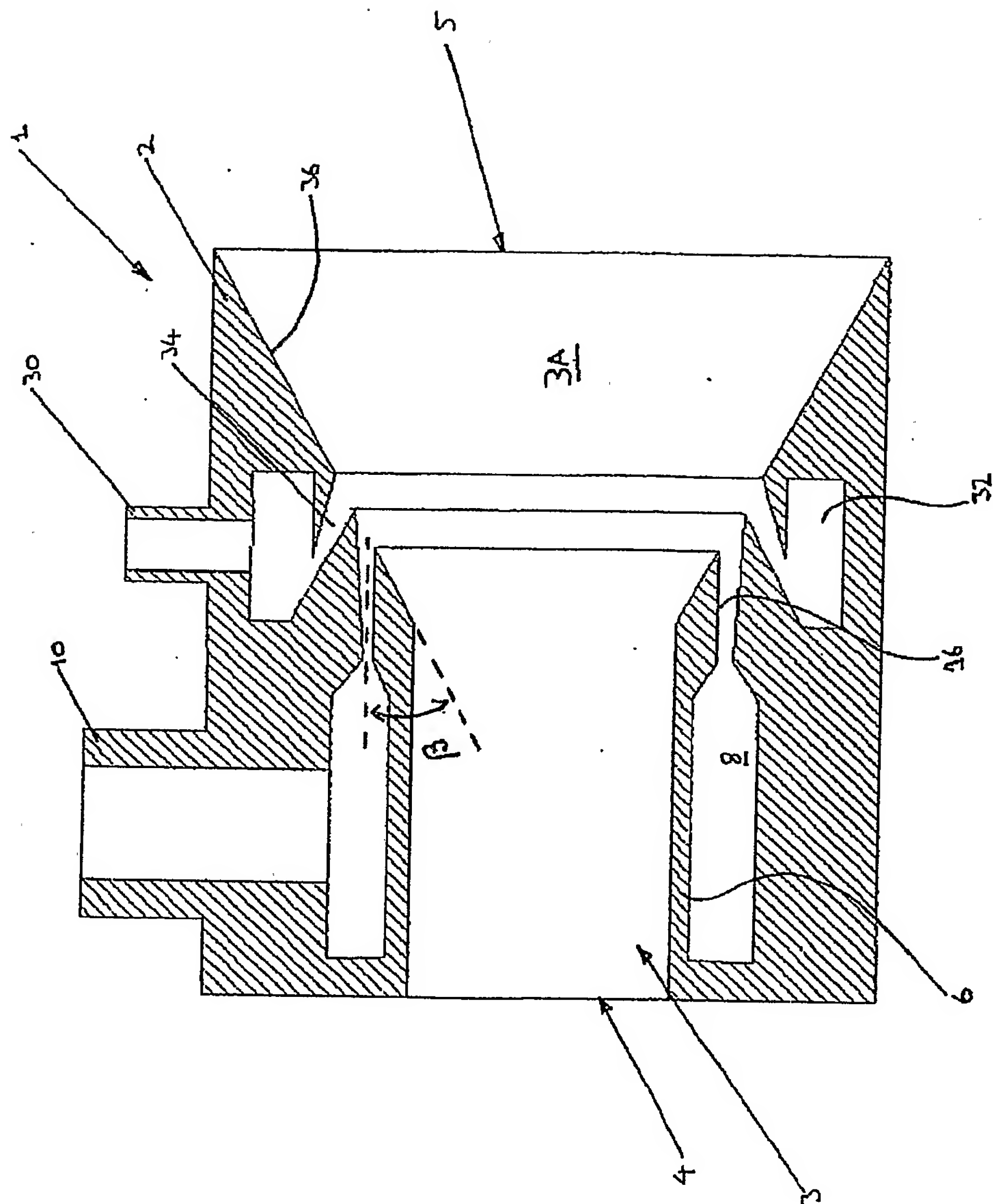
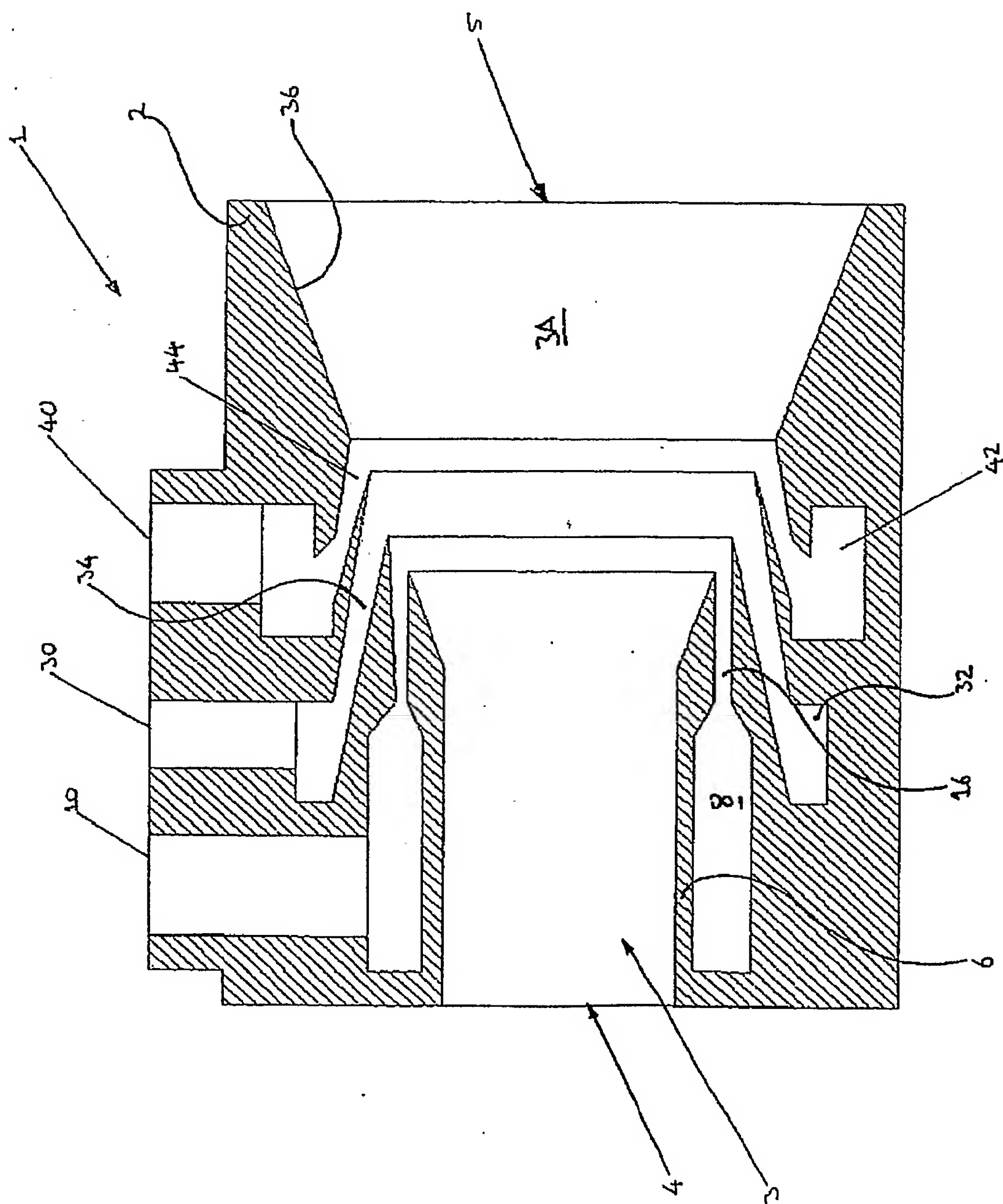
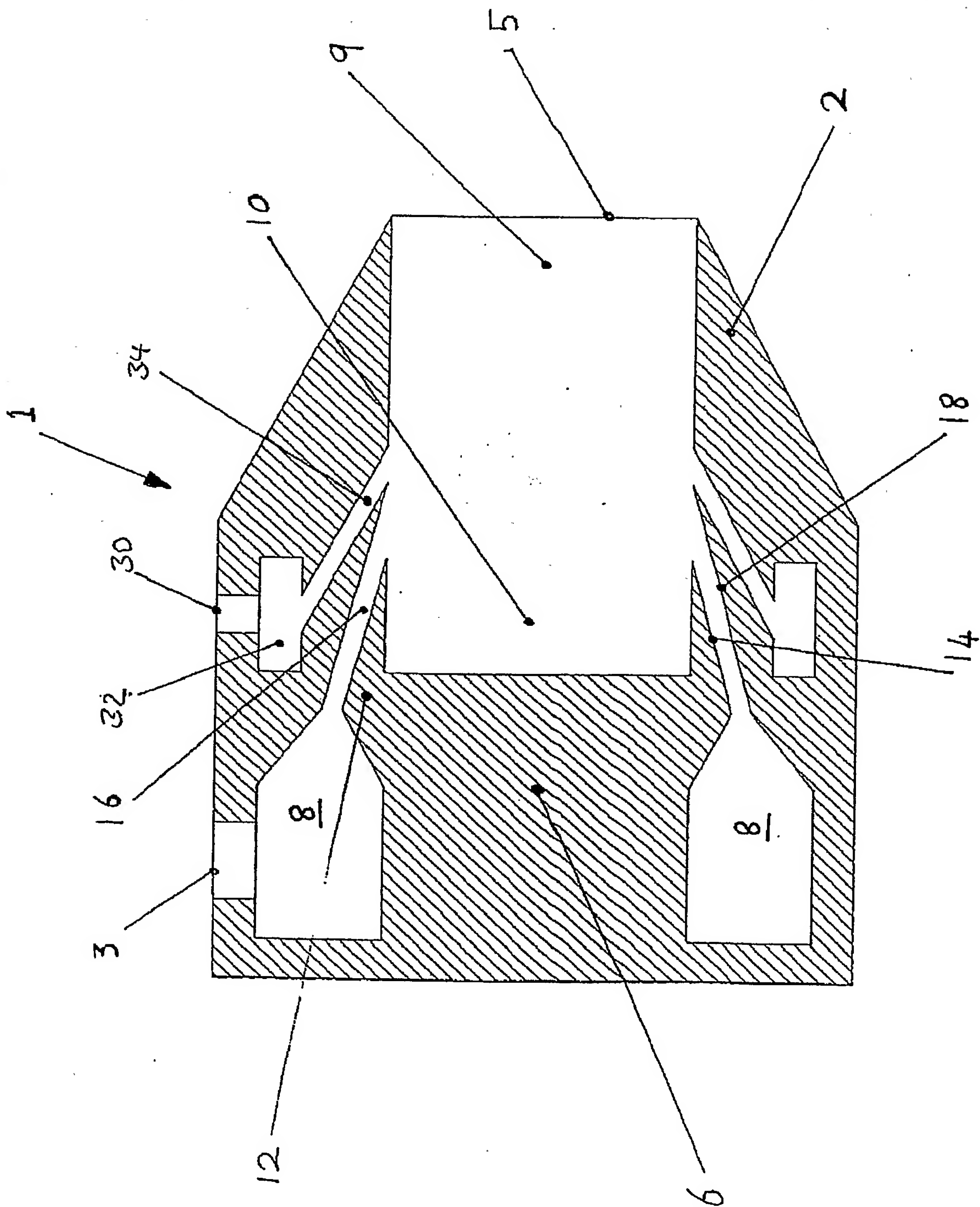


Figure 14











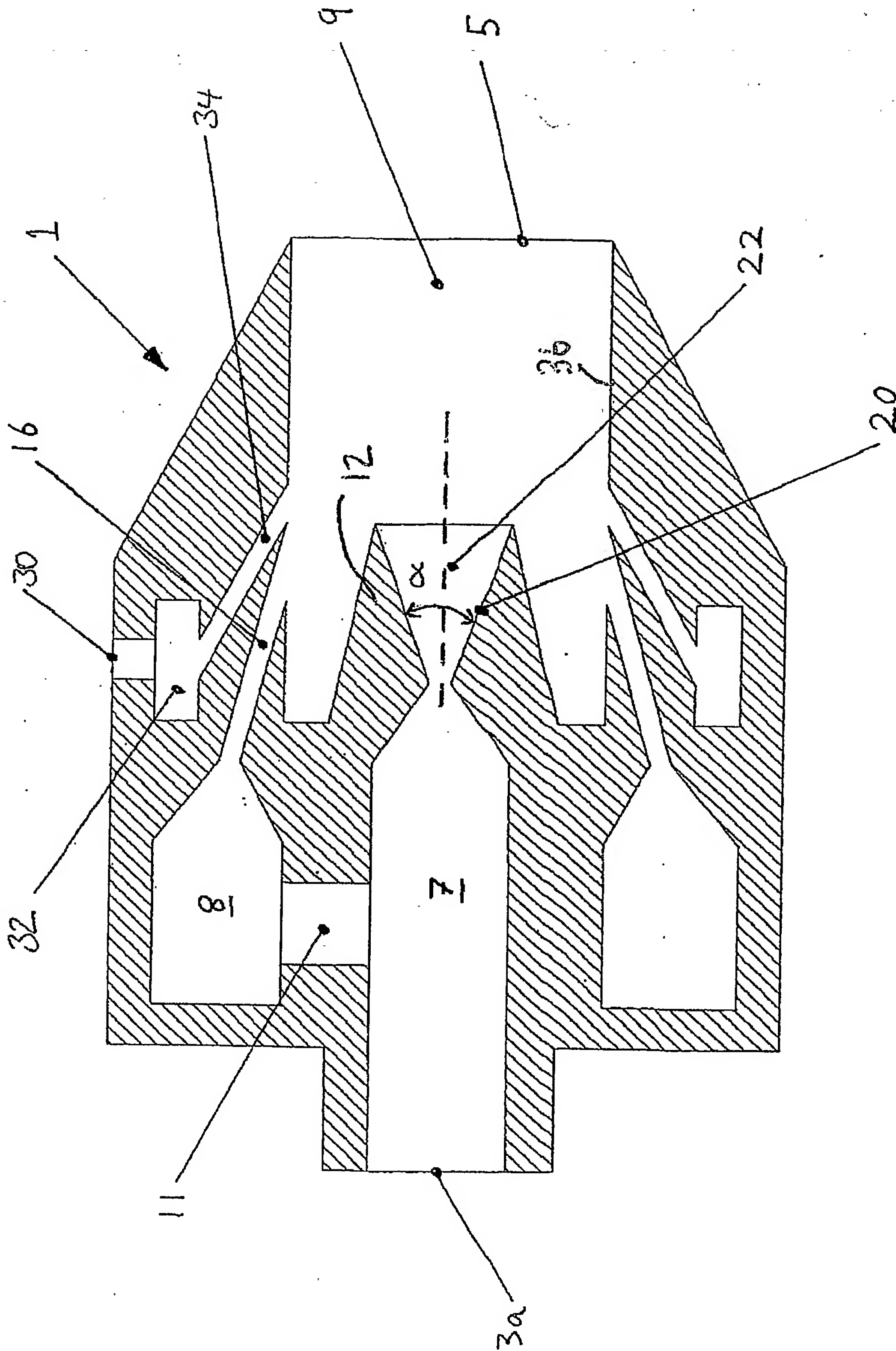


FIGURE 17



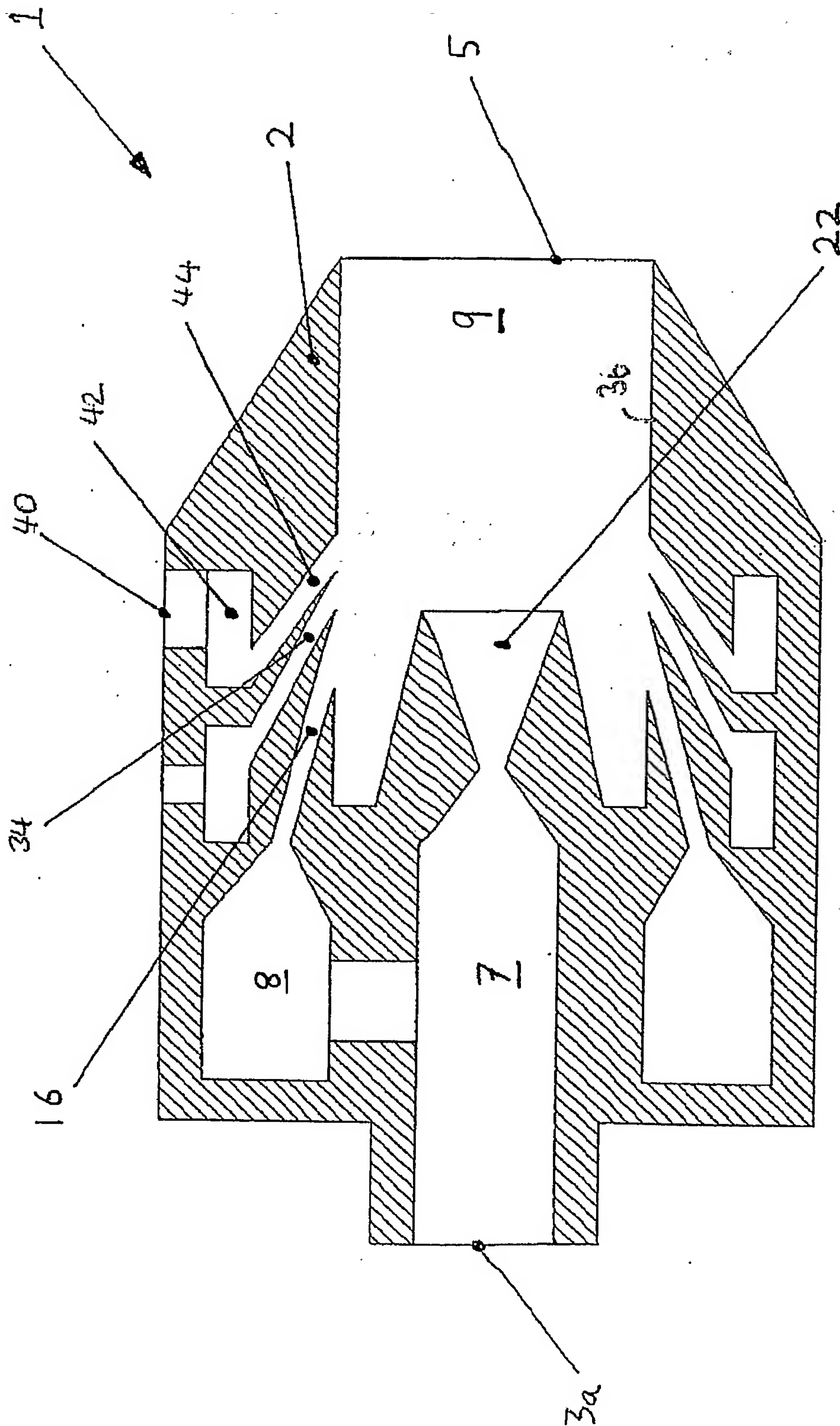


FIGURE 18



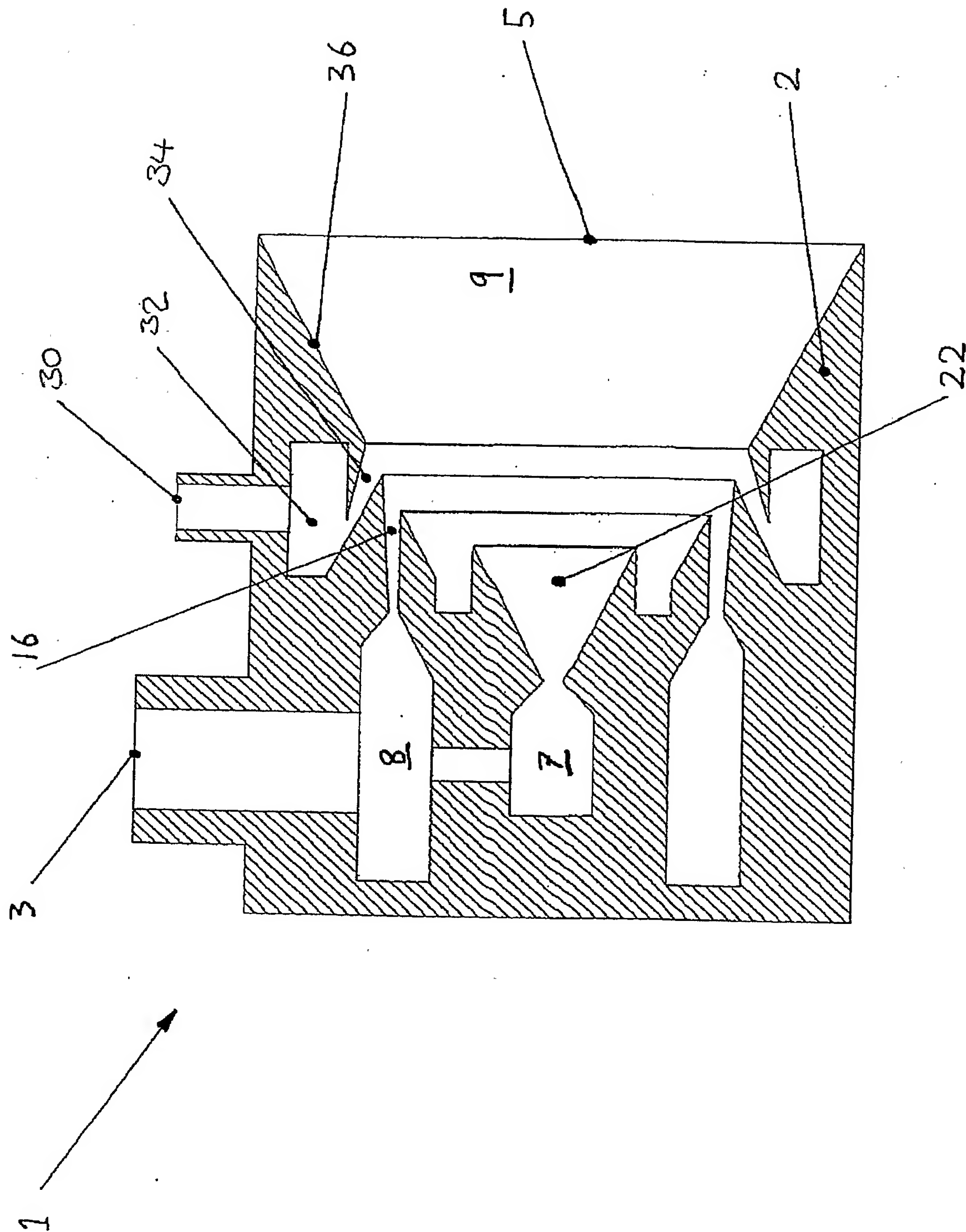
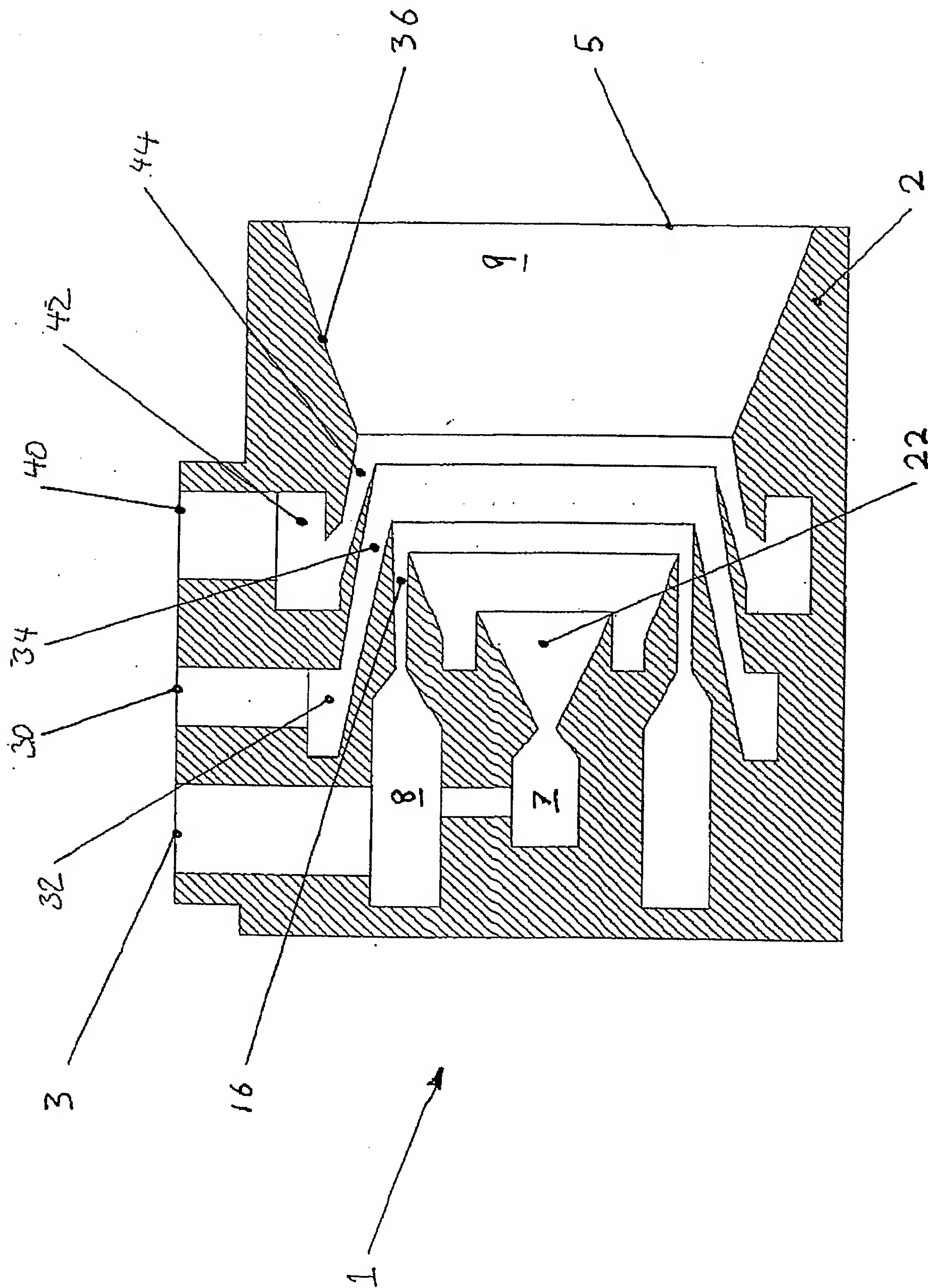


FIGURE 19









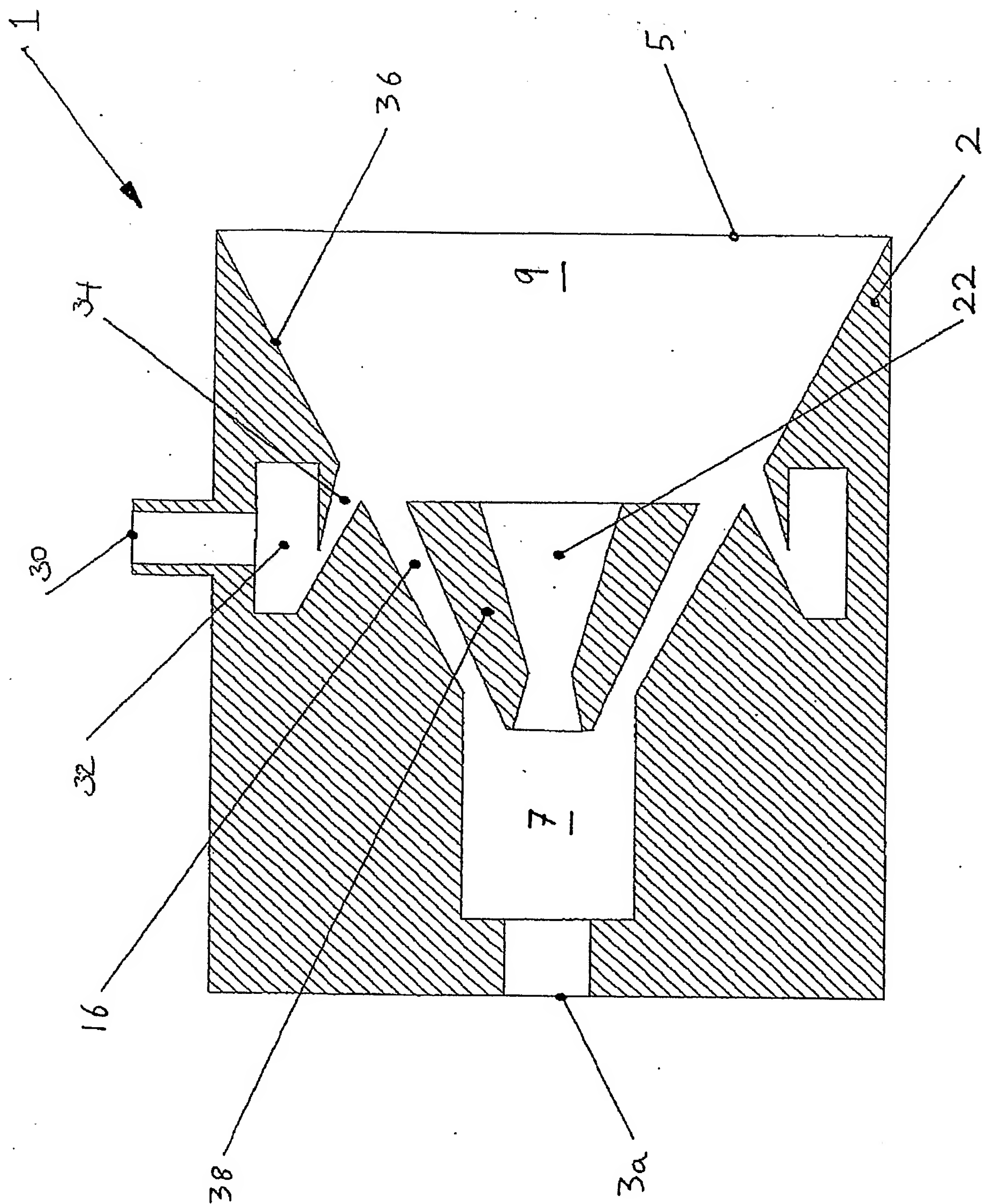


FIGURE 22-



Performance Data

% Volume

Measurement Taken at 10m and 5° off Centre Line

99.5 percentile of all measured particles

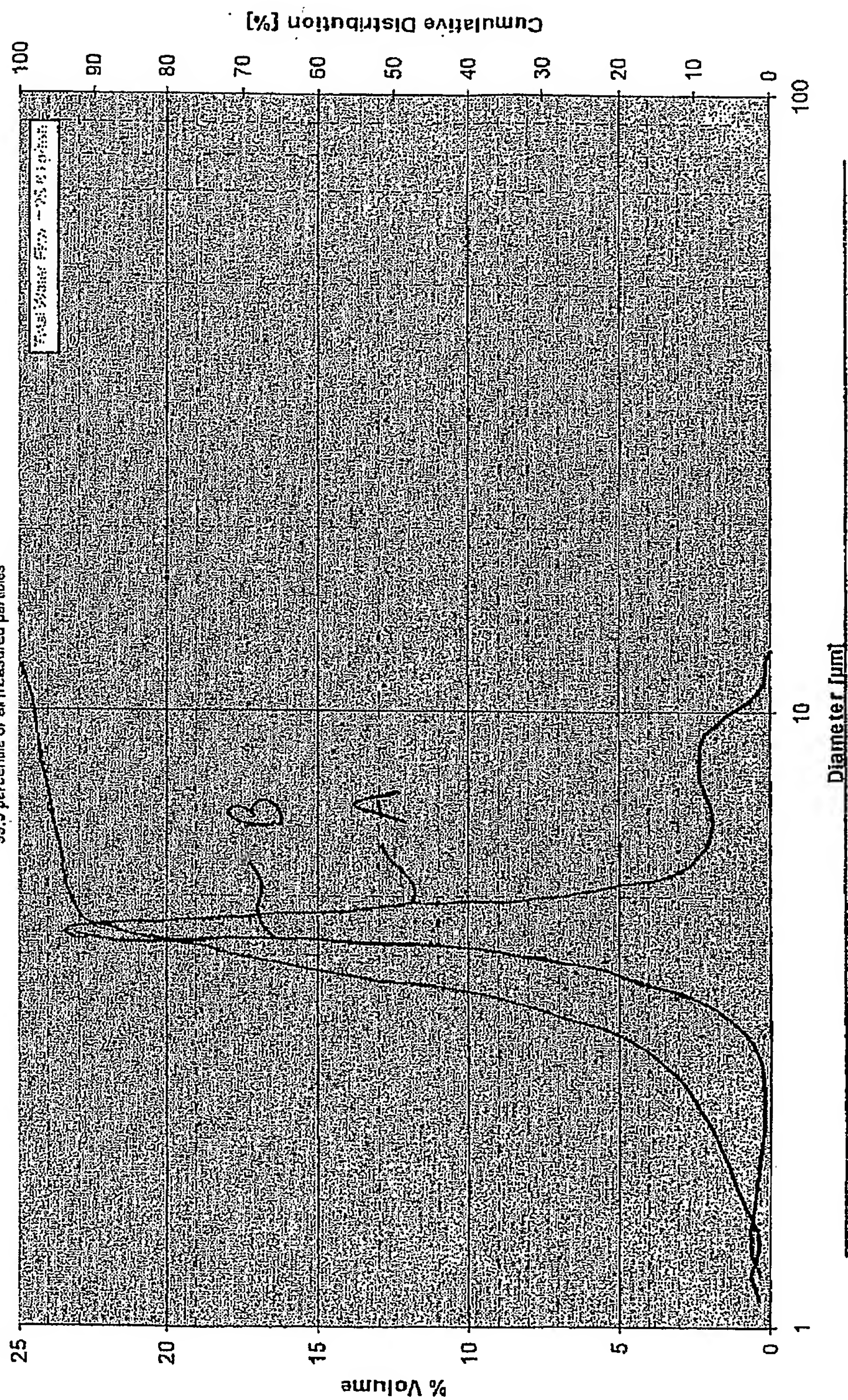


FIGURE 23

